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QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

UNDER-THE-WING (UTW) BOILER PLATE NACELLE AND CORE EXHAUST NOZZLE DESIGN REPORT

OCTOBER 1976

BY:

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AIRCRAFT ENGINE GROUP

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(NASA-CR-135008) QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE) UNDER-THE-WING (UTW) BOILER PLATE NACELLE AND CORE EXHAUST NOZZLE DESIGN REPORT (General Electric Co.) 104 p HC A06/MF A01 CSCL 21E G3/07

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FOREWORD

The major objective of the QCSEE Program is to develop and demonstrate the technology required for propulsion systems for quiet, clean, and economically viable commercial short-haul aircraft. The program includes design, fabrication, and testing of a gear-driven, variable-pitch turbofan engine for under-the-wing (UTW) installation and a gear-driven, fixed-pitch turbofan engine for over-the-wing (OTW) installation. Both experimental engines will utilize the F101 core and LP turbine.

This report is comprised of two independent sections documenting the design of the Boiler Plate Nacelle and the Core Exhaust Nozzle for the QCSEE UTW engine. The material presented within this two-part document consists of the design criteria and the mechanical design of the nacelle and nozzle to be used in the aeromechanical and acoustical evaluation of the engine. Also presented are the analytical techniques and the engineering evaluation used to arrive at the final design. Every major component of the UTW nacelle, except the pylon closeout, is capable of being adapted for subsequent testing on the OTW engine.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

PART I

BOILER PLATE NACELLE

SECTION I

INTRODUCTION

This document presents the design criteria and the aeromechanical design of the under-the-wing (UTW) boiler plate nacelle to be used in the initial aeromechanical and acoustical evaluation of the UTW engine in the NASA QCSEE program. The structural, mechanical, and material characteristics of the QCSEE boiler plate nacelle and components are similar to those of recently developed test nacelles for the Quiet Engine program and CFM56 series engines. The design intent is to provide the lowest-cost structure consistent with functional and reliability requirements. The use of heavy gage metal in sheet extrusion and bar form, in combination with high strength fasteners, has proved to be a good, economical way to make durable and fatigue-resistant nacelle components for testing engines of this type.

Economics in the QCSEE program were accomplished by designing major nacelle components to be interchangeable between the various propulsion system configurations. Most of the UTW boiler plate nacelle hardware will be used to make up the over-the-wing (OTW) propulsion system. A composite flare-type fan exhaust nozzle (designed and built for the UTW composite nacelle configuration) will be adapted for use in the UTW boiler plate nacelle tests. The design and operation of the nozzle will be described in the Under-The-Wing Composite Nacelle Design Report.

Another economy measure employed in this effort was to limit the number of different acoustic treatment panels to one complete set of single-degree-of-freedom (SDOF) panels, plus an additional panel set (bulk absorber) for the hybrid inlet. The material required for additional panels will be purchased and kept on hand to reduce turn-around time, if the initial acoustic test results do not meet QCSEE noise reduction goals. The results of the UTW boiler plate nacelle acoustic tests will be used to define the acoustic configuration of the UTW composite nacelle.

SECTION II

NACELLE DESCRIPTION

Presented in this section is a description of the boiler plate nacelle hardware. The nacelle is being fabricated by GE/Mojave under a detail design and build contract. This hardware has been designed for ease of replacement of the various acoustic treatment and hard-wall panels which will be tested

A. INLET

Testing of the UTW and OTW engines will require three boiler plate inlet configurations. The NASA Quiet Engine "C" bellmouth inlet will be utilized for aerodynamic engine mapping and baseline acoustic evaluation. A massive inlet suppressor, also from the Quiet Engine "C" program, will be utilized to isolate aft-end noise and provide additional information for acoustic evaluation. A hybrid inlet, featuring elevated throat Mach number and multiple acoustic suppression design capability, will be employed for the aeromechanical and acoustical evaluations. All inlets will be mechanically decoupled from the engine to prevent overload of the composite fan frame due to excessive engine motion/vibration. A typical inlet-to-test-stand mounting system at the Peebles test site is shown in Figure 1. The typical decoupled or "load-break" joint is shown in Figure 2. The air seal is provided by an open-cell foam, Scottfelt, bonded to half of the flange and pressed against the other half. The acoustic seal is provided by a lead foil in a vinyl cover. The two seals aerodynamically and acoustically simulate the hard-joint condition of the final composite propulsion system assembly.

The bellmouth inlet package consists of a fiberglass/honeycomb bellmouth and a cylindrical casing that satisfies the static aerodynamic requirements for a low Mach number inlet (Figure 3). A new adapter casing has been fabricated from 6061 aluminum to aerodynamically transition the existing Quiet Engine Program bellmouth flowpath to the new QCSEE flowpath (Figure 4).

The massive inlet suppressor from the Quiet Engine "C" program, consists of a fiberglass/honeycomb lip and a four-ring splitter assembly which provides an "overkill" configuration of SDOF acoustic treatment (Figure 5). An acoustic study confirmed the acceptability of this inlet if the aerodynamic transition casing could be acoustically treated with a bulk absorber. Consequently, a second major adapter casing has been fabricated from 6061 aluminum, which is identical aerodynamically to the one procured for the bellmouth package but is acoustically treated with Scottfelt (bulk absorber) for the four-ring splitter configuration (Figure 6). A concurrent aerodynamic study indicated that no significant fan inlet flow distortion would be introduced through the use of the four-ring splitter inlet on the UTW engine, even at the higher flow Mach numbers associated with take-off power on the QCSEE. The only precaution recommended by the study was that the spacing between the

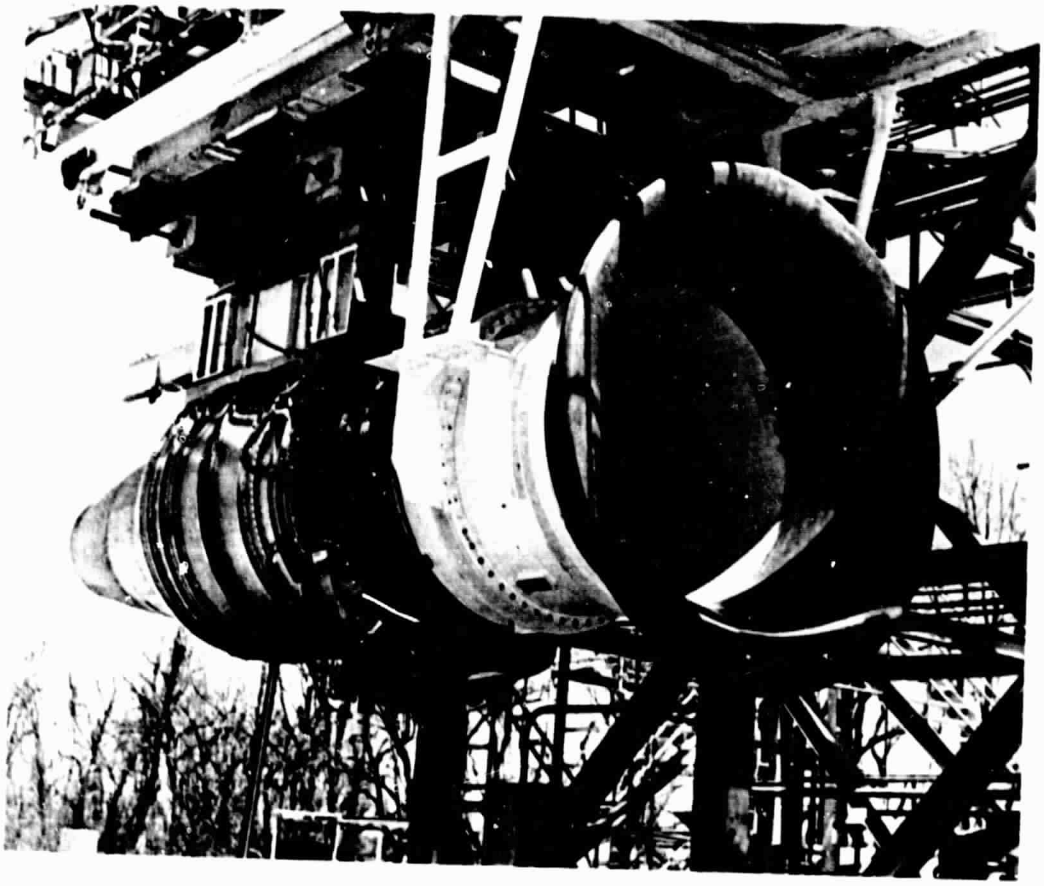

Figure 1. Inlet on Test Stand at Peebles Proving Ground.

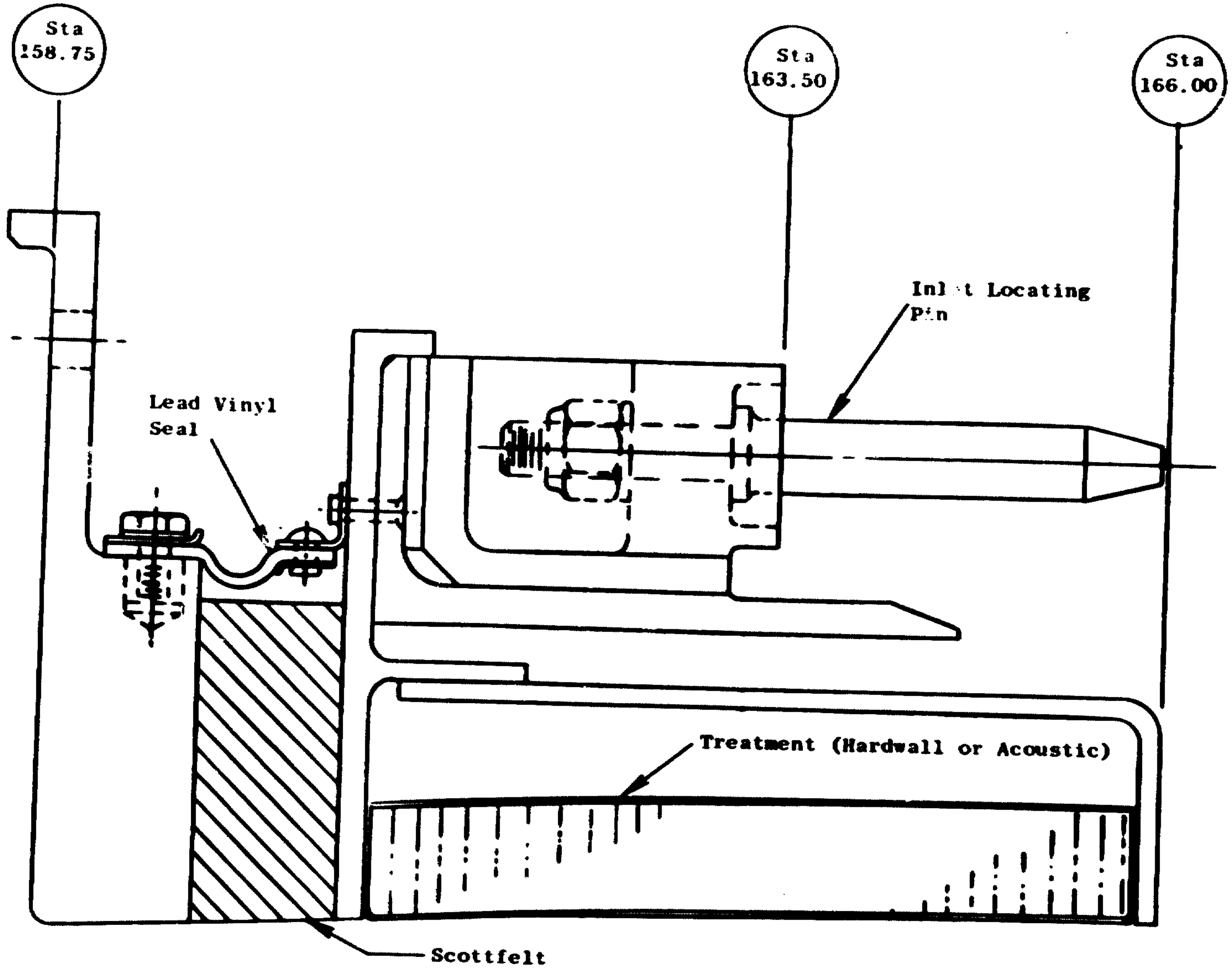

Figure 2. Inlet Decoupling Joint.

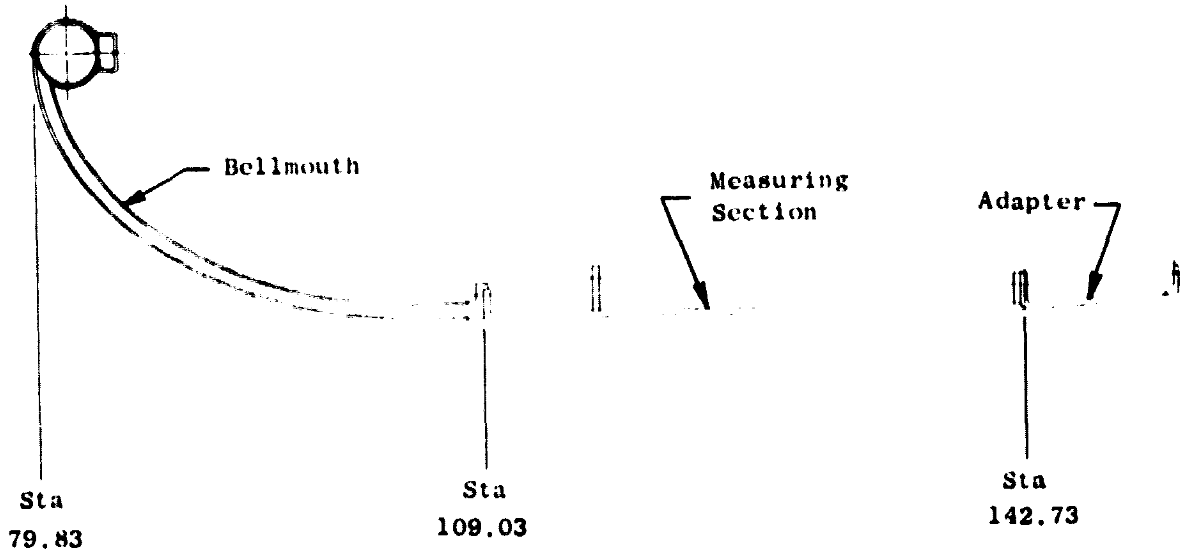

Figure 3. Boiler Plate Inlet, Bellmouth.

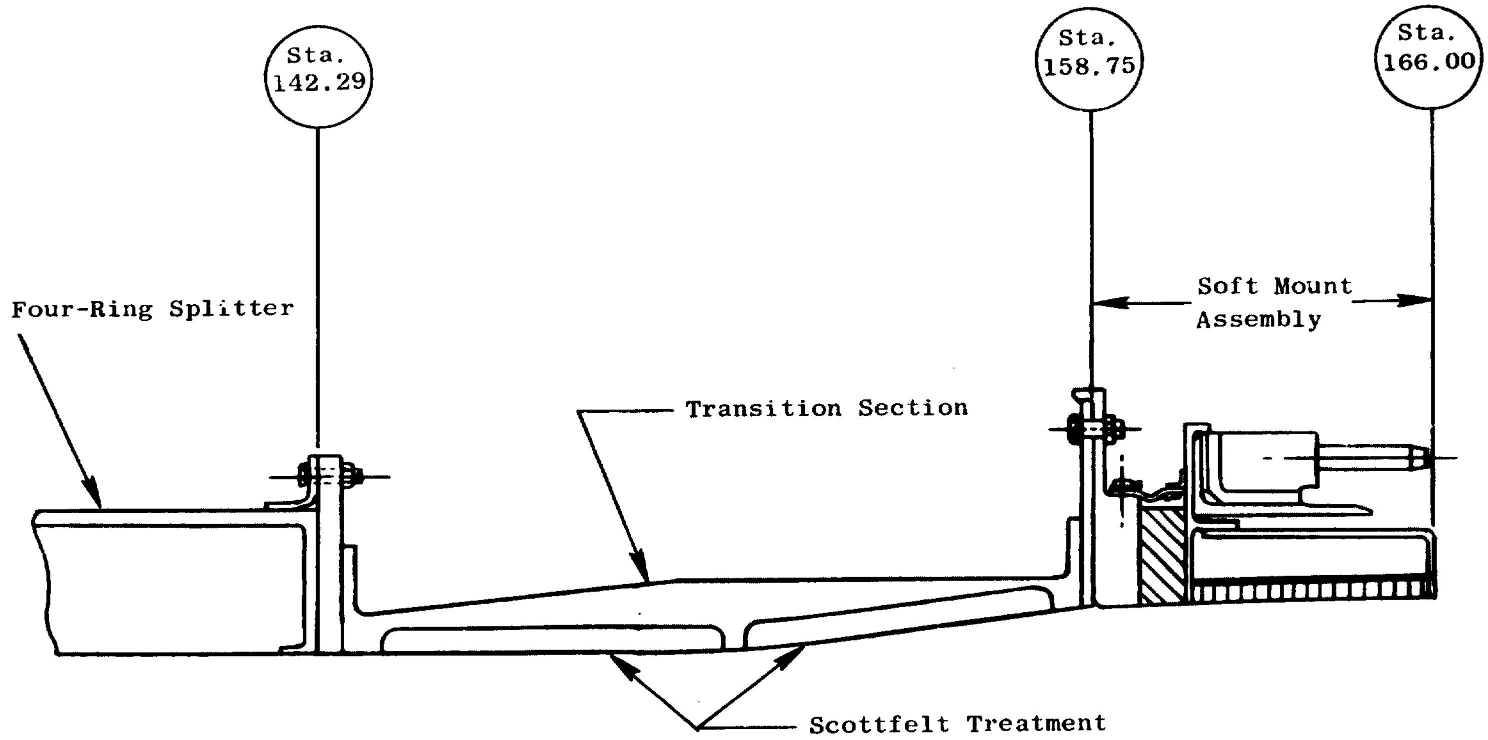

Figure 4. Bellmouth Transition Section.

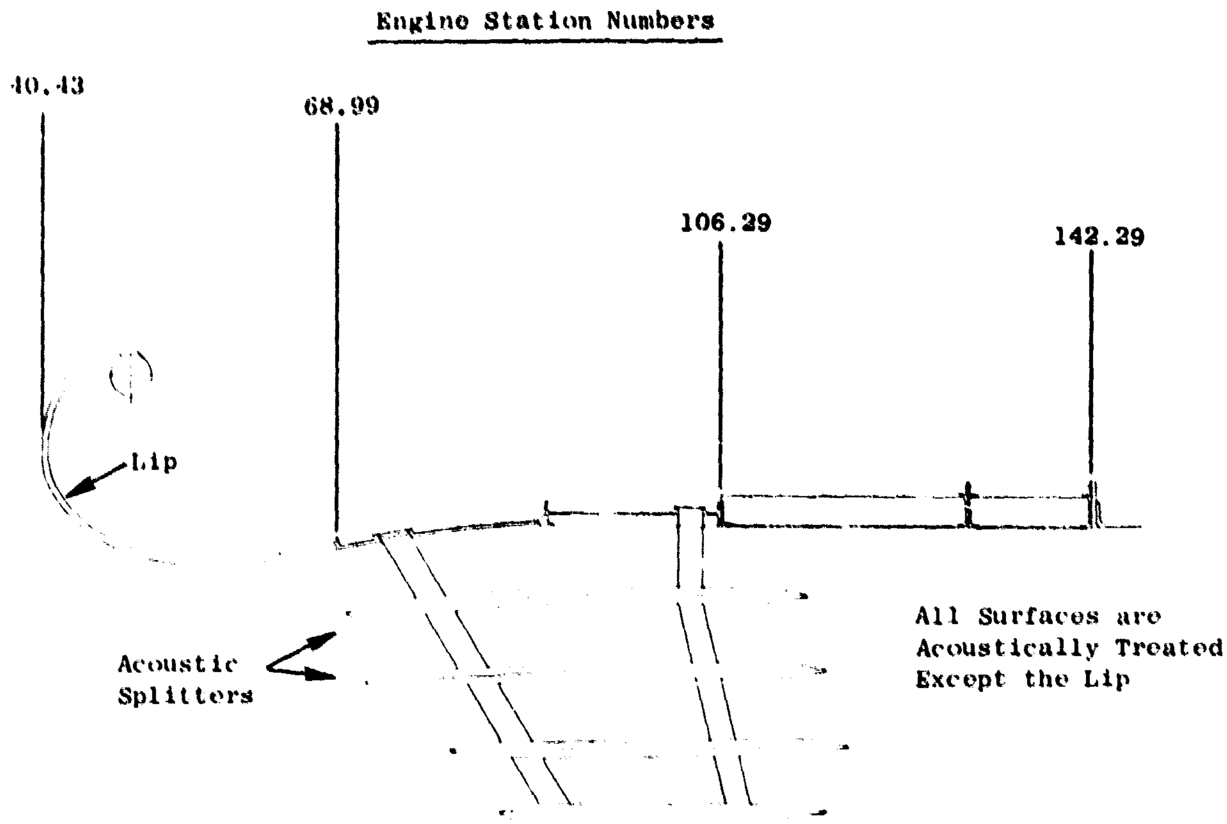

Figure 5. Massive Suppressor Inlet with Four-Ring Splitter.

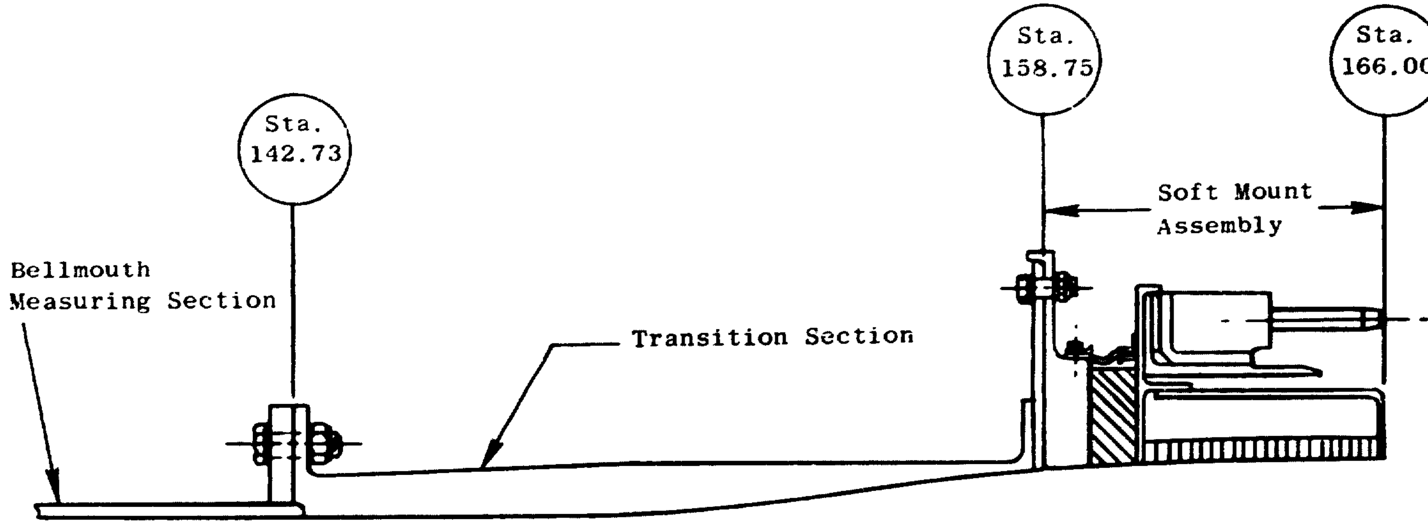

Figure 6. Four-Ring Splitter Transition Section.

splitter trailing edges and the fan spinner be maintained at the same length as the Quiet Engine "C" [a distance of 86.4 cm (34 in.)]. This criterion established the required length of both the bellmouth and the four-ring splitter transition sections.

The hybrid inlet package (see Figure 7) includes a fiberglass/honeycomb aeroacoustic lip and a 6061 aluminum structural shell that provides the attachment bosses for interchangeable acoustic and hard-wall panels. The acoustic configuration has three treatment thicknesses in accordance with the acoustic design philosophy. The treatment will have one axial parting, which provides greater future acoustic treatment flexibility. A typical single-degree-of-freedom acoustic panel fabrication will consist of an aluminum perforated-faceplate stretch formed to the correct contour and bonded to a honeycomb core which, in turn, is bonded to a fiberglass backing sheet. Acoustic specifications for the planned panel constructions of the single-degree-of-freedom and the bulk absorber panels will be described in a separate section.

B. FAN COWL

The UTW fan cowl is an aluminum structural sheet and stringer assembly consisting of two semicircular door structures that provide the attachment capability for interchangeable sets of acoustic-treatment and hard-wall panels. A single-ring acoustic splitter which matches the acoustic configuration will be supported by the fan cowl through six airfoil-shaped struts. Core cowl access is accommodated by the hinged door construction of the fan cowl. The fan cowl doors are decoupled from the fan frame to prevent the transmission of excessive nacelle weight to the fan frame. The primary structural attachment is made through two heavy-duty, piano-type hinges located at the top edge of the door assemblies (Figure 8). All forward and aft fan cowl loads are transmitted through the hinge to the facility structure. Vertical and side loads are transmitted to the test stand through two telescoping struts which are attached to the door assemblies approximately 0.35 radians (20°) above the horizontal centerline of the engine.

The variable UTW fan nozzle and actuator system will be designed and procured as a component of the composite nacelle assembly and will be utilized in both the composite and boiler plate nacelle configurations. It is fully operable and attaches as an assembly to the fan cowl. The design philosophy of the actuator and track systems is to provide identical actuator stroke/nozzle positioning for both boiler plate and composite assemblies. This approach should eliminate calibration problems between the two configurations (Figure 9).

C. SPLITTER

The acoustic splitter (Figure 10) is a double sandwich structure consisting of aluminum sheet metal skins, machined rings, and honeycomb cores. The leading- and trailing-edge closeouts are aerodynamically machined aluminum rings. The design is similar for any sandwich construction, in that the primary load path is carried through the skins and closeout rings. The final

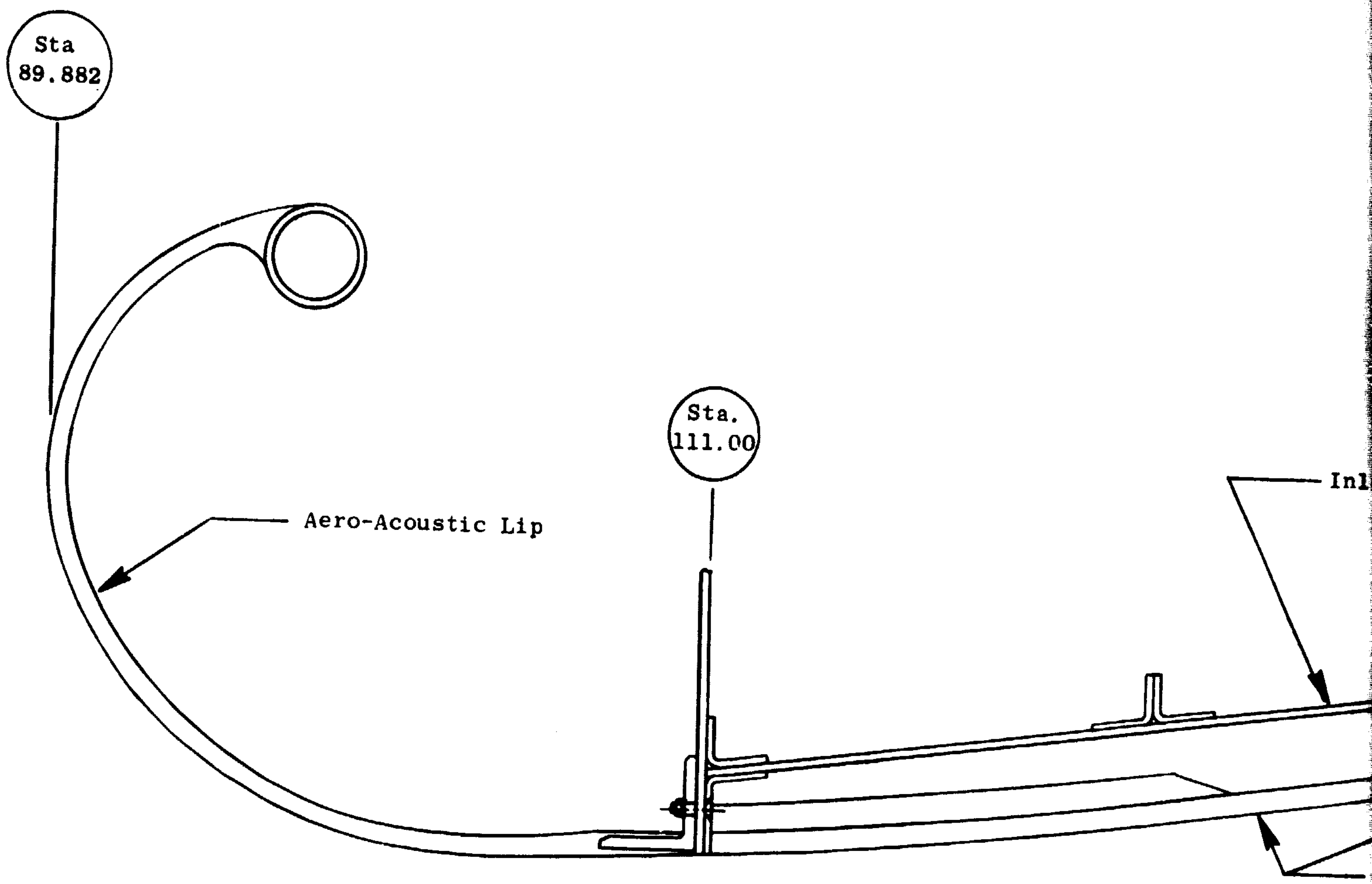

Figure 7. Hybrid Inlet A

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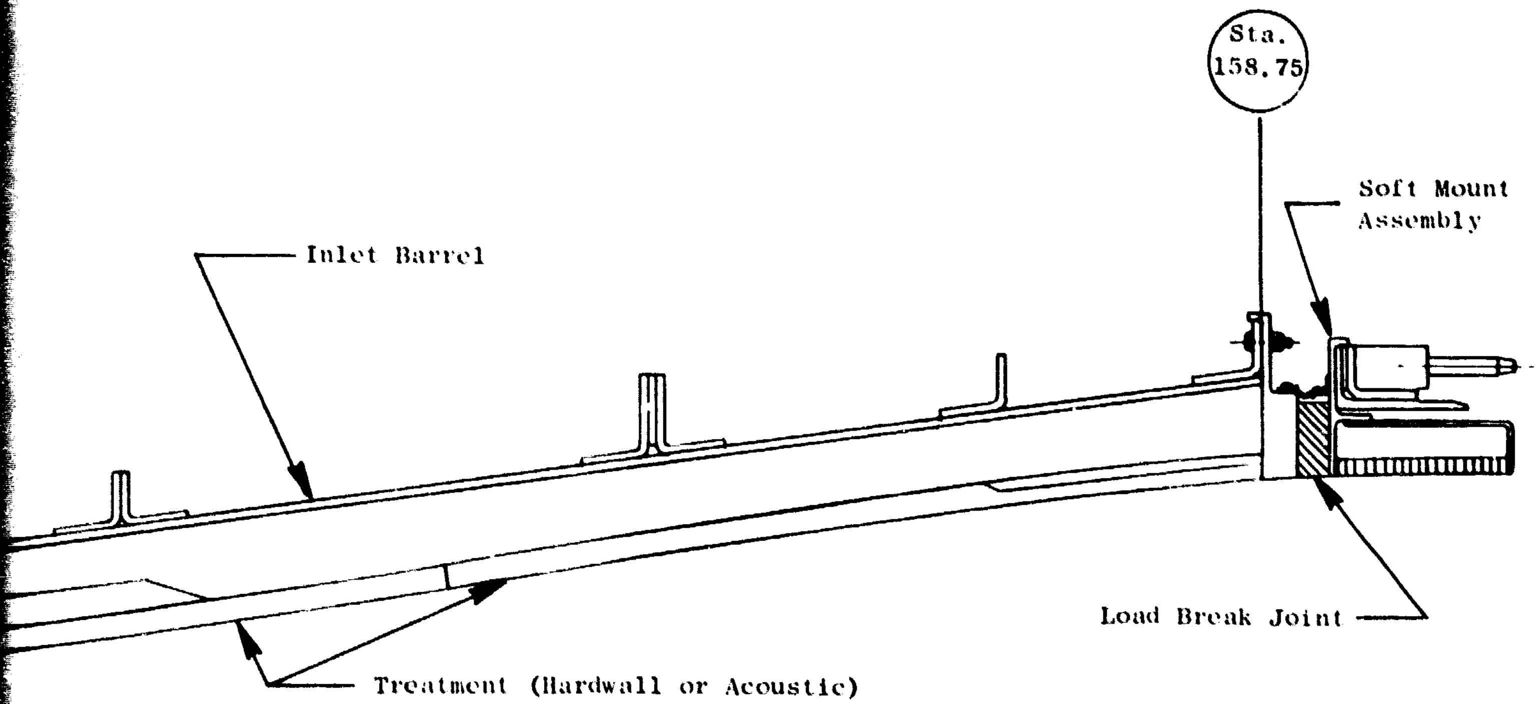

gure 7. Hybrid Inlet Assembly.

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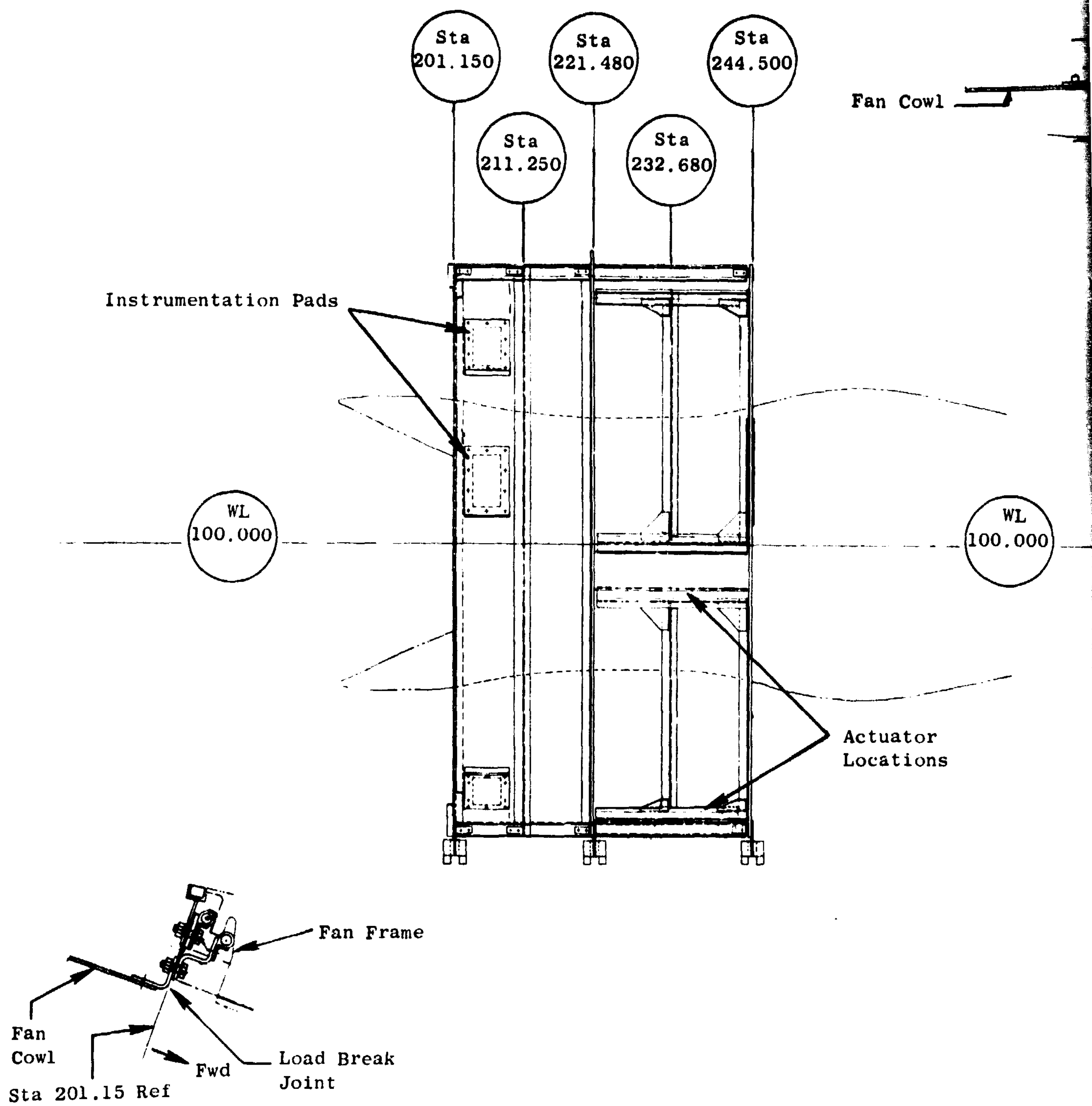

Figure 8. Fan Door

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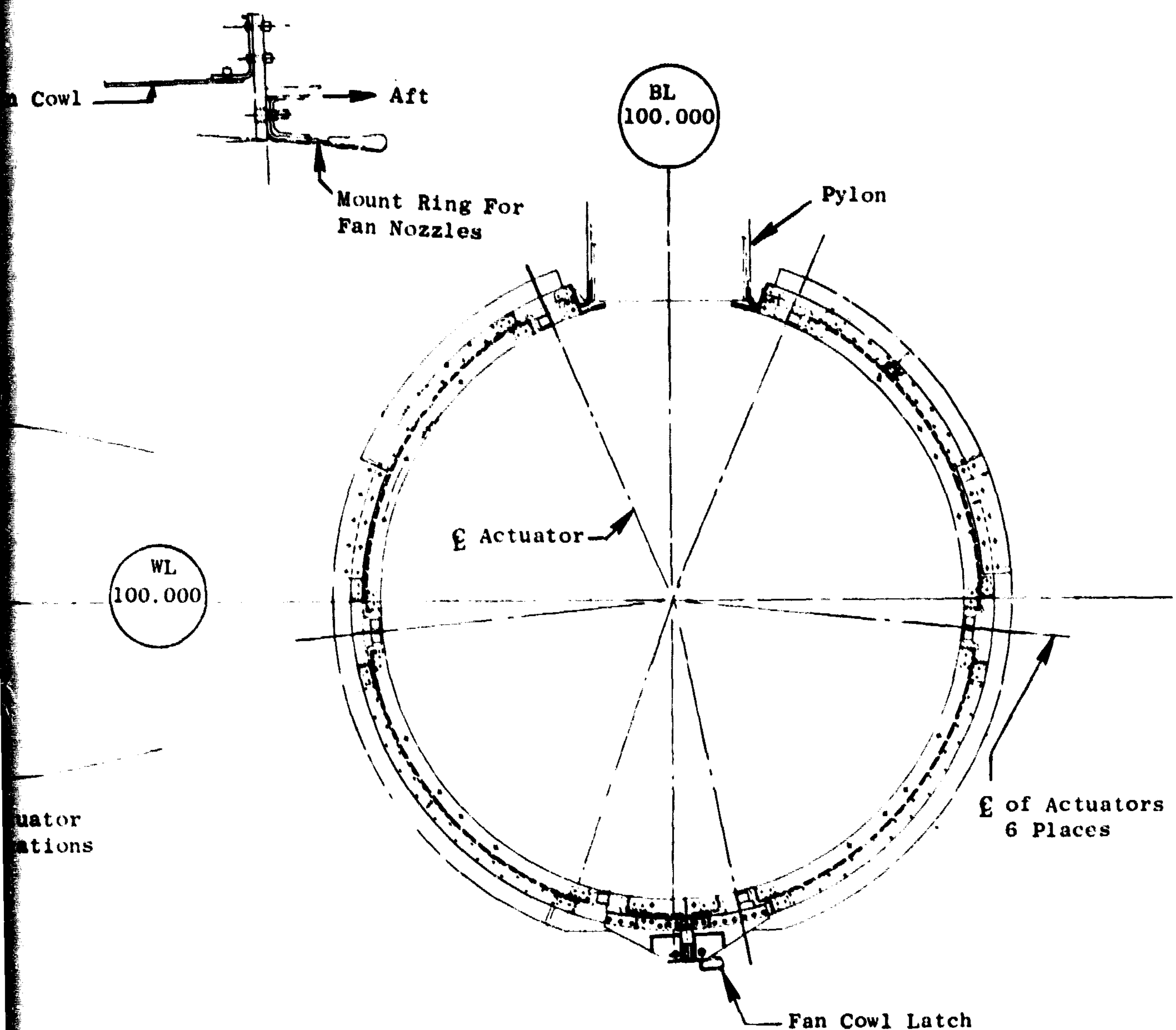

Figure 8. Fan Doors.

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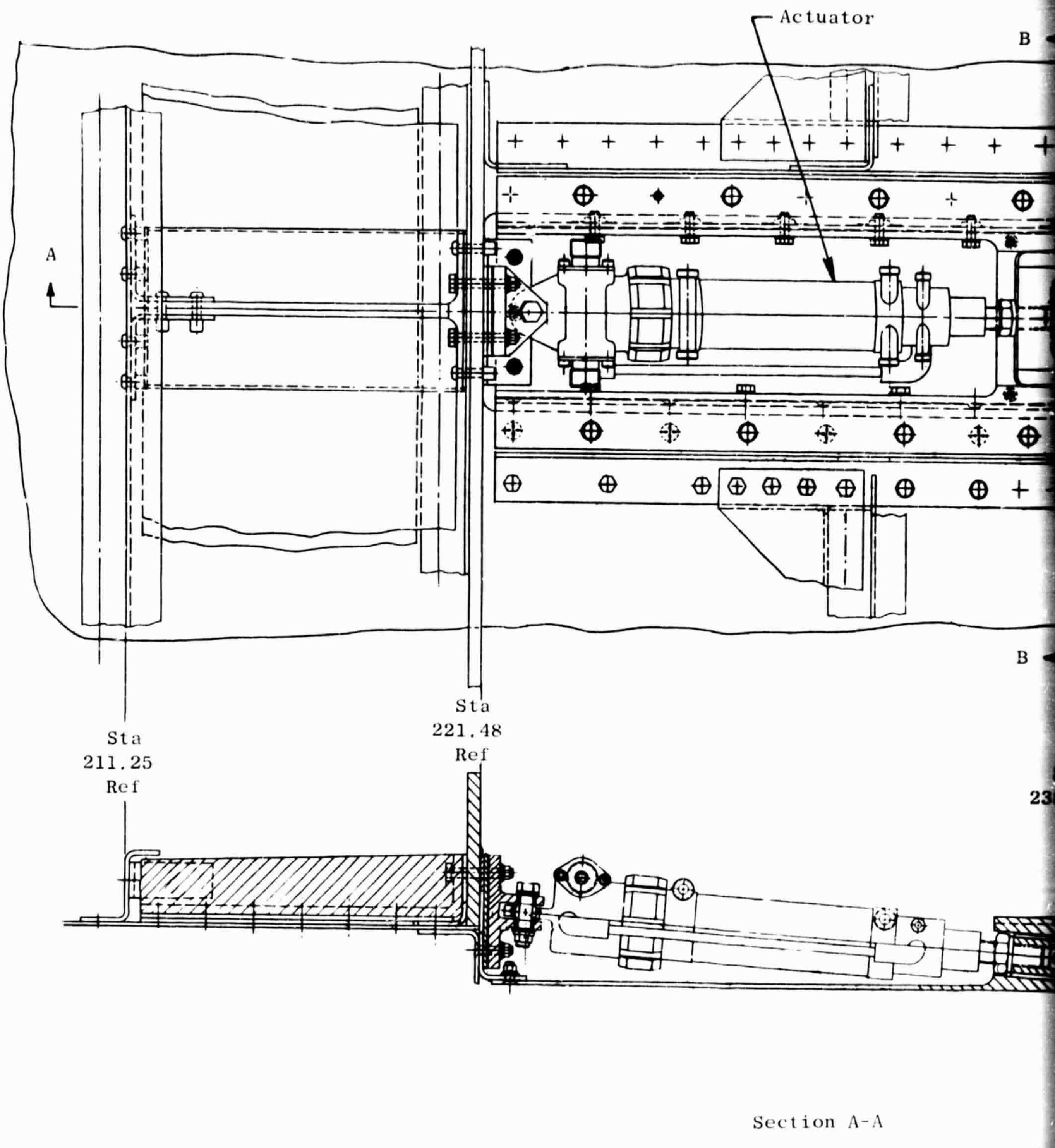

Figure 9. Boiler Plate Nacelle

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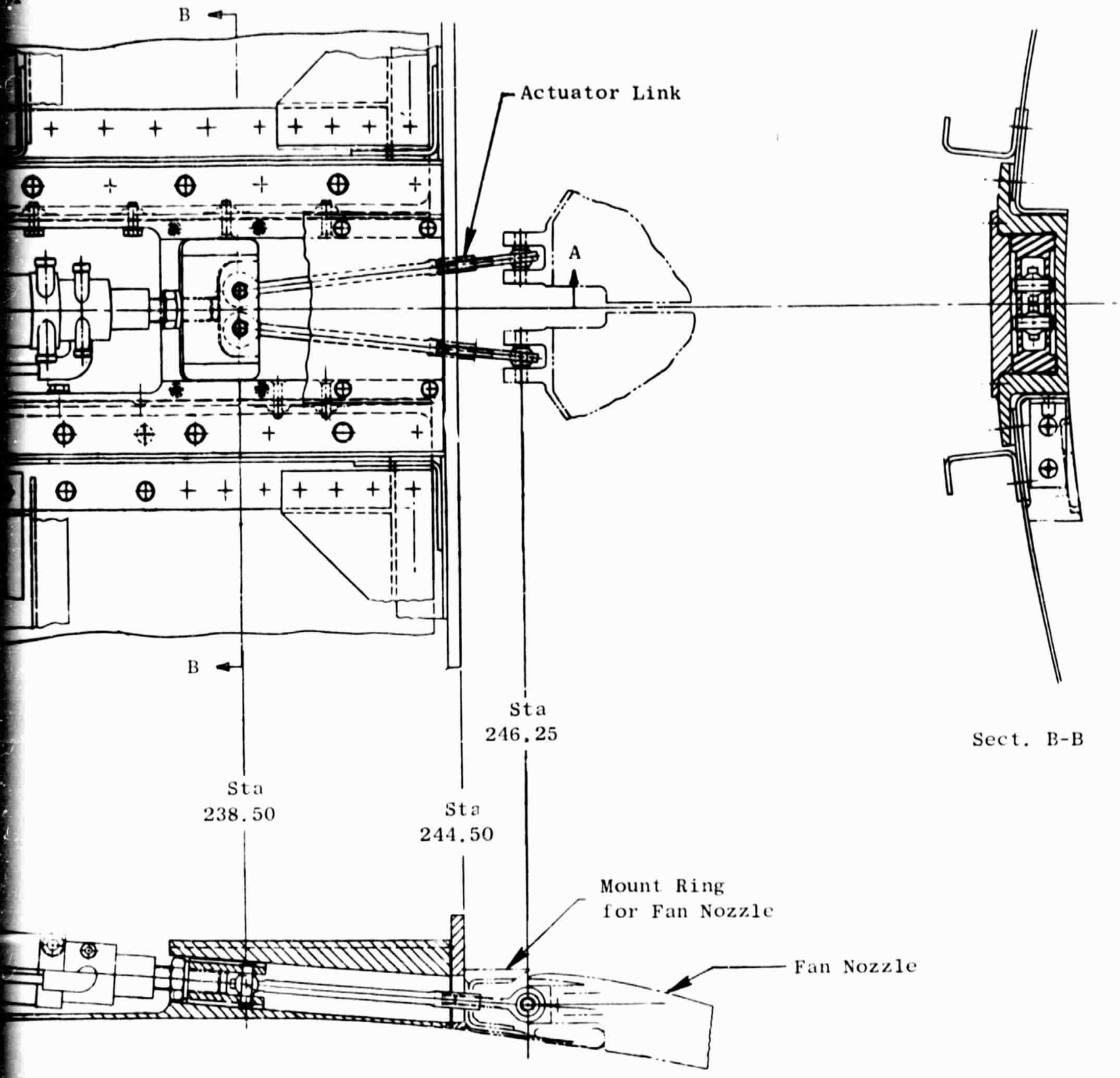


A-A

oiler Plate Nacelle Actuator Assembly.

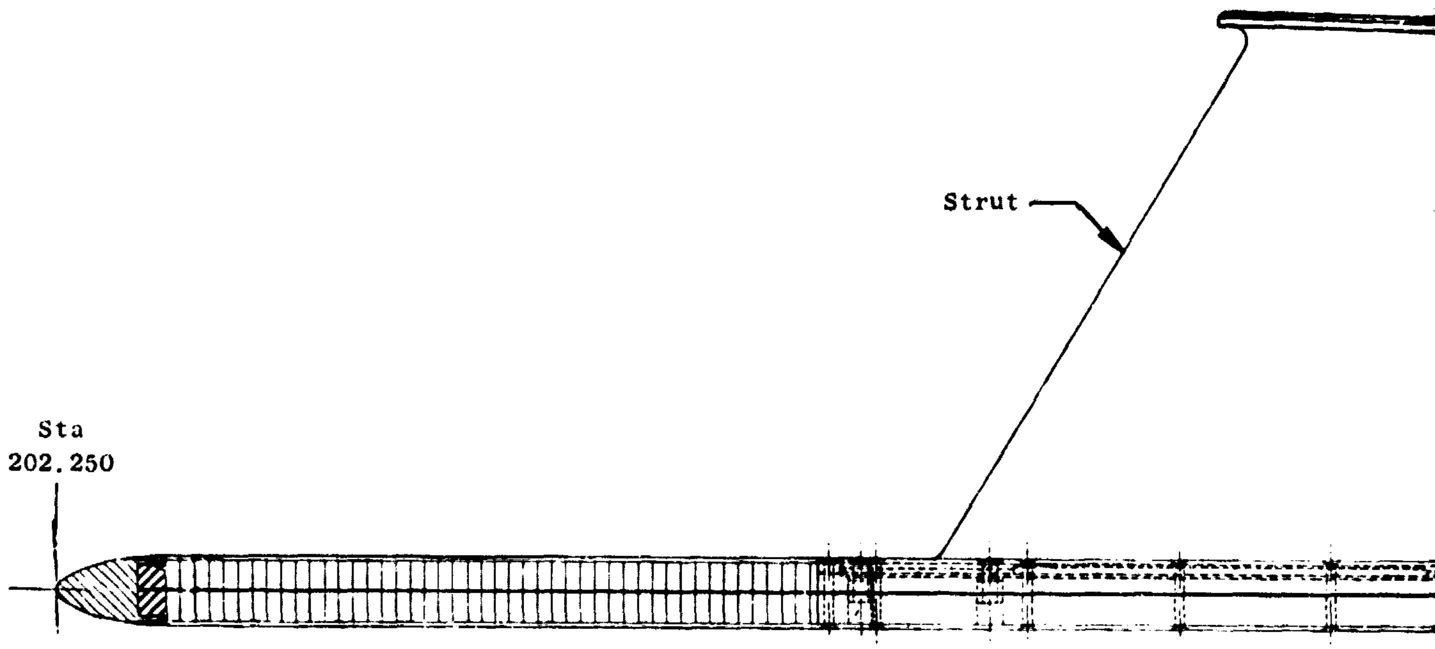
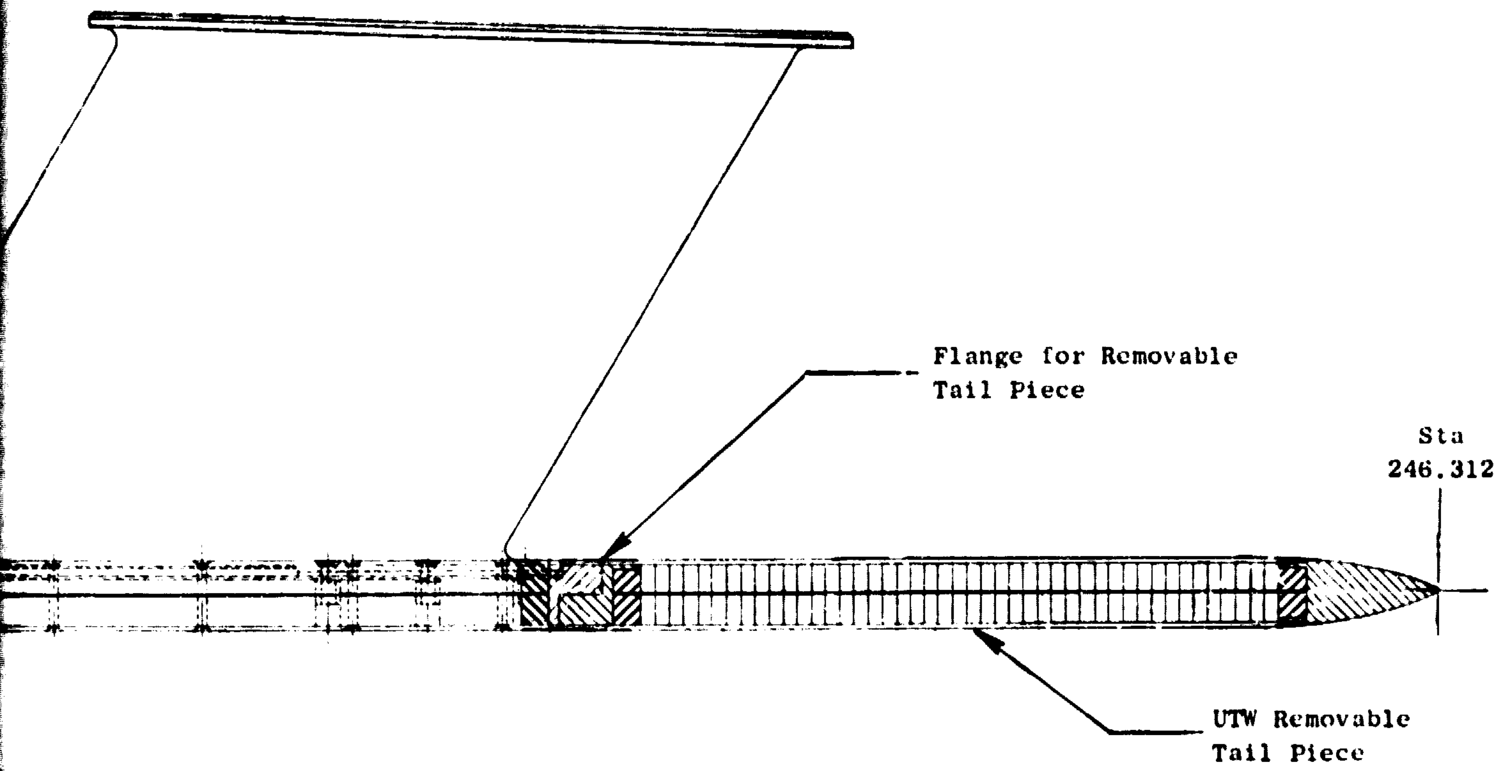


Figure 10. Splitter As



ure 10. Splitter Assembly.

assembly consists of two semicircular structures supported from the fan cowl by six stainless steel air-foil-shaped struts. Silicon seals have been applied to the mating edges of the splitter halves to dampen potential vibratory movement during engine testing.

The splitter is designed to be removable. Filler pieces, which replace the strut feet, will be inserted in the fan doors during engine operation without the splitter. A flange is provided near the trailing edge of the splitter. Two trailing-edge pieces are procured that match the common flange and provide interchangeability between the UTW and OTW configurations. The length of the UTW splitter is approximately 101.6 cm (40 in.) and the OTW 76.2 cm (30 in.).

The fabrication procedure for the splitter follows: after the aluminum rings have been riveted and bonded with EA 901/B1 (Hysol Corporation) to the inner aluminum perforated faceplate, it is positioned in the tool as shown in Figure 11. Hexabond adhesive, a product of Hexcel Corporation, is applied to one side of the honeycomb (Hexcel CR III - 1/4 - 5052) with an adhesive weight of 0.088 to 0.107 kg/m^2 (0.018 to 0.022 lb/ft^2). The Hexabond adhesive, which is always placed on the faceplate side, provides good strength characteristics for its weight with essentially no hole plugging. After the honeycomb is trimmed and positioned, the ring closeouts are filled with a core splice adhesive per GE Specification P6TF1, and the middle septum plate is bonded to the honeycomb with Metalbond 329 supported film adhesive. This assembly is cured under pressure before proceeding to the next step.

The next step is to assemble the outer sandwich structure in a manner similar to that described above, but in reverse order. Following this second bonding operation, the part is removed from the tool (Figure 12).

The final operation is to cover all exposed rivet heads. This is accomplished by bonding thin strips of 181-gage fiberglass cloth impregnated with adhesive around all of the closeouts (Figure 13).

D. CORE COWL

The UTW core cowl is a stainless steel structural shell that supports interchangeable sets of acoustic or hard-wall panels. It has a forward interface (Marman-type joint) with the fan frame, and an aft interfacing slip joint with the core nozzle. Access to the compressor and turbine is provided by the hinged-door construction of the core ducting. Prior to opening, the core doors and apron assembly are temporarily attached to and supported by the pylon through a set of pins.

The core cowl will employ shop-air cooling, bleed air from the fan duct, and radiation shields to maintain a safe operating environment for the epoxy resins that will be used in the construction of the acoustic and hard-wall panels. Cooling requirements are greater than those needed by the composite configuration (using only fan air and radiation shields) which utilizes polyimide adhesives with temperature capabilities higher than epoxy resins. The cooling system analysis is presented in a later section.

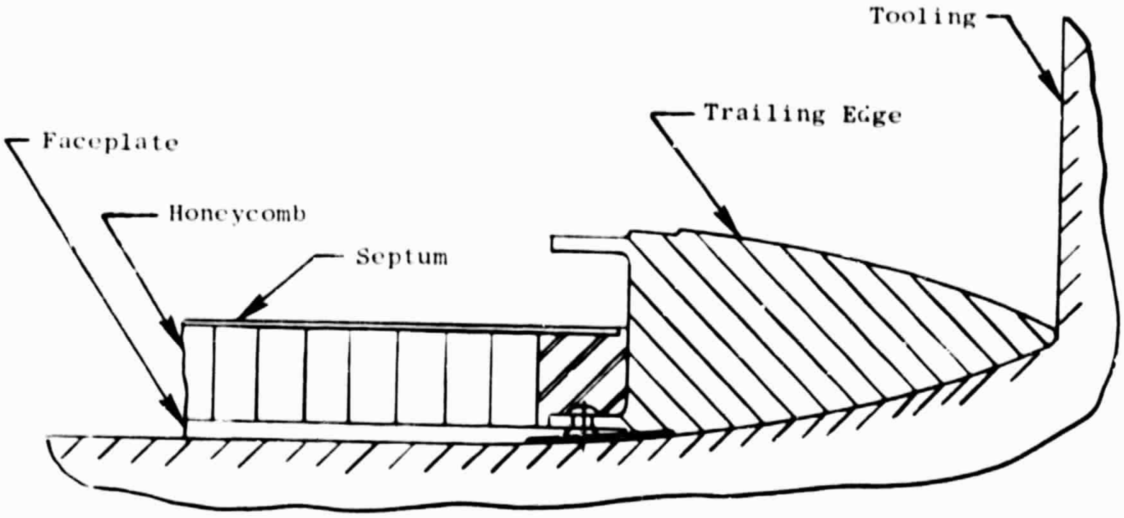


Figure 11. Splitter Tooling Schematic.

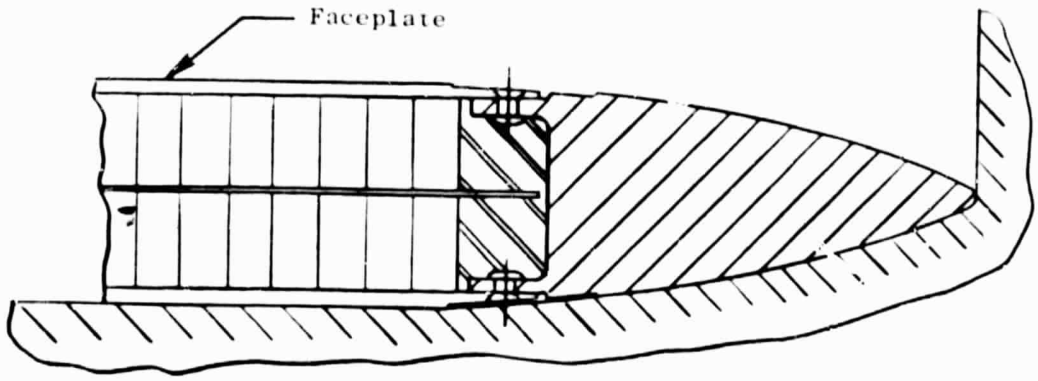


Figure 12. Splitter Tooling Schematic/Final Operation.

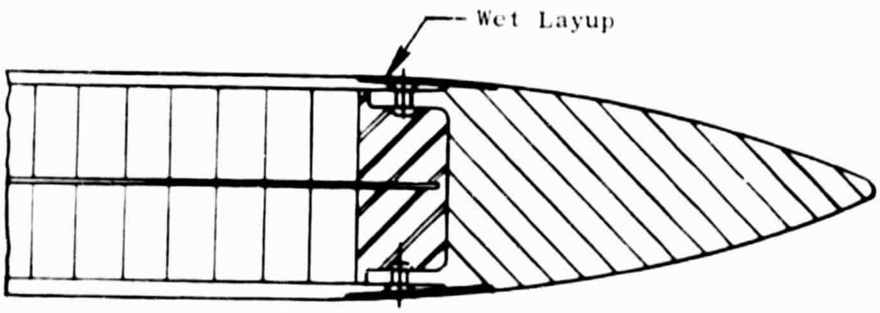


Figure 13. Splitter Complete.

The design and construction of the core cowl is complicated by its proximity to the engine and engine components, the acoustic treatment flexibility, and the high-temperature condition in the aft compartment. The structural shell is comprised of cones and cylinders consisting of two semicircular door assemblies that are attached to the apron assembly through four point hinges and one hook on each side. This system is mechanically clamped to the frame as described above. There are numerous cutouts in the structure, such as those for the beta regulator and the scavenge pump. Seal interfaces exist on all edges of this assembly, as well as the fire seal located at Station 239 (Figure 14).

E. PYLON

The pylon assembly is the primary structural support system for the fan exhaust duct assembly. It is bolted to the engine mount system, transmitting fan cowling and nozzle loads directly to the facility. The inner skirt and hinge are decoupled from the pylon during engine operation and attached to the pylon when the doors are open. Core door loads are transmitted to the fan frame during engine testing. The pylon upper support assembly and boattail assembly are hard mounted to the test stand structure. The aluminum fairings that make up the pylon forward assembly are attached to the low carbon steel pylon upper support structure through structural fittings. The pylon fairings have 35.56 x 76.20 cm (14 x 30 in.) removable access panels on both sides and provide the aerodynamic contour of the pylon. The removable fairing provides accessibility for core instrumentation inspection (Figure 15).

The boattail portion (Station 244.5 to Station 314.0) of the overall pylon assembly has only a seal interface with the forward part and is always hard mounted to the test stand structure. An access panel, exposing the rear engine mount, is located on the left-hand side (aft looking forward). There is a detachable panel along the bottom edge, permitting removal of the core nozzle while in the test stand.

In addition to the structural attachment to the facility, the pylon upper support structure and forward assemblies have interfaces with the fan cowl through piano-type hinges at the top of the fan cowl door assemblies, with the splitter assembly through a seal along its top edges, and with the apron assembly through a fillet seal at the lower edge of the pylon. Final rigging and structural attachment must be made as a total assembly on the tooling mandrel at Mojave. During final installation at Peebles, the total system is fitted as a complete, integral system by aligning the system centerline established by the tooling mandrel with the engine installed in the facility.

F. ACOUSTIC PANELS

(1) Single Degree of Freedom

All SDOF and hard-wall panels are similar in design. The difference between the hard-wall panels and the treated panels is the substitution of a

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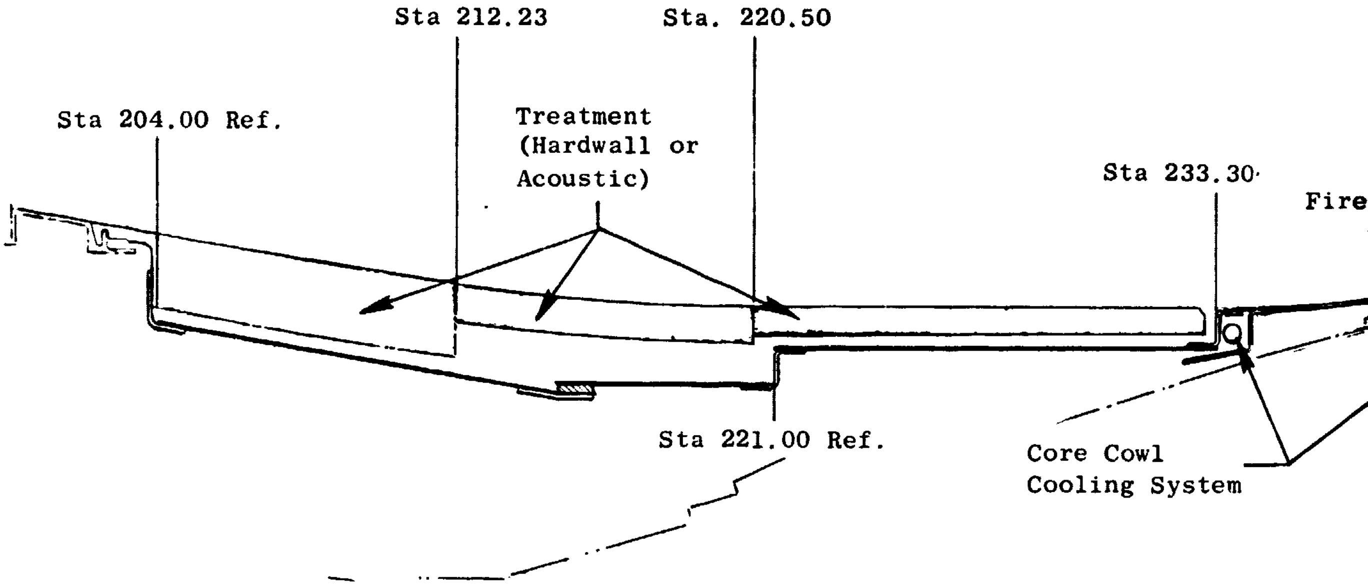
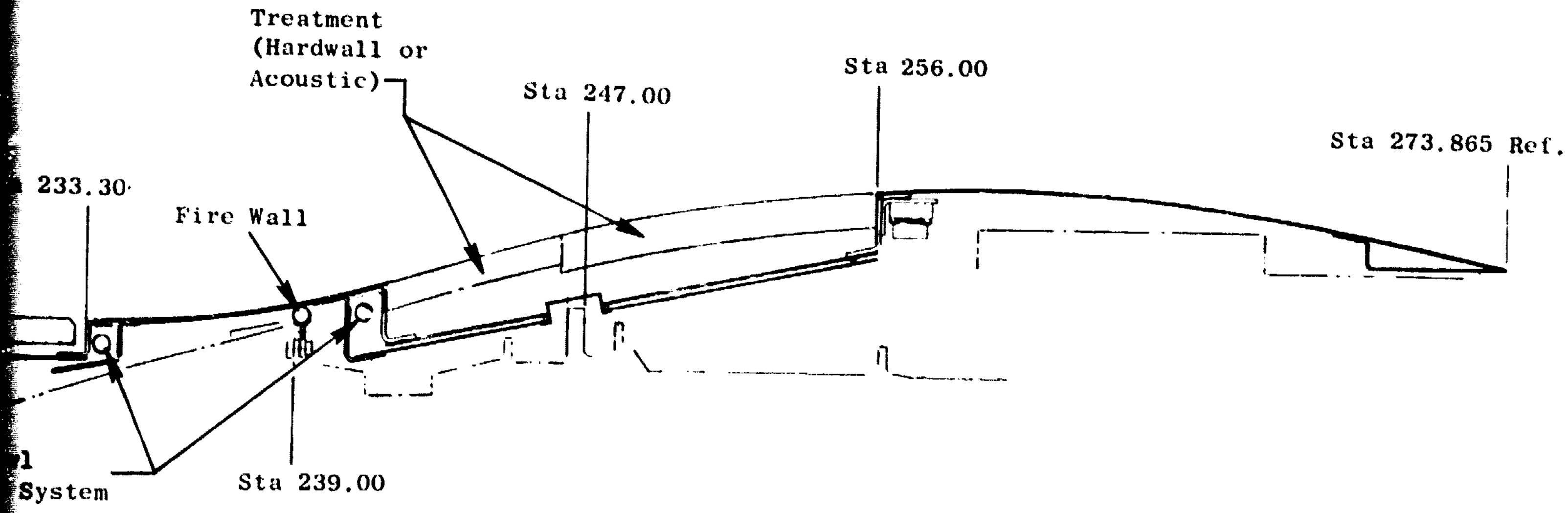


Figure 14. Core C



ure 14. Core Cowl Assembly.

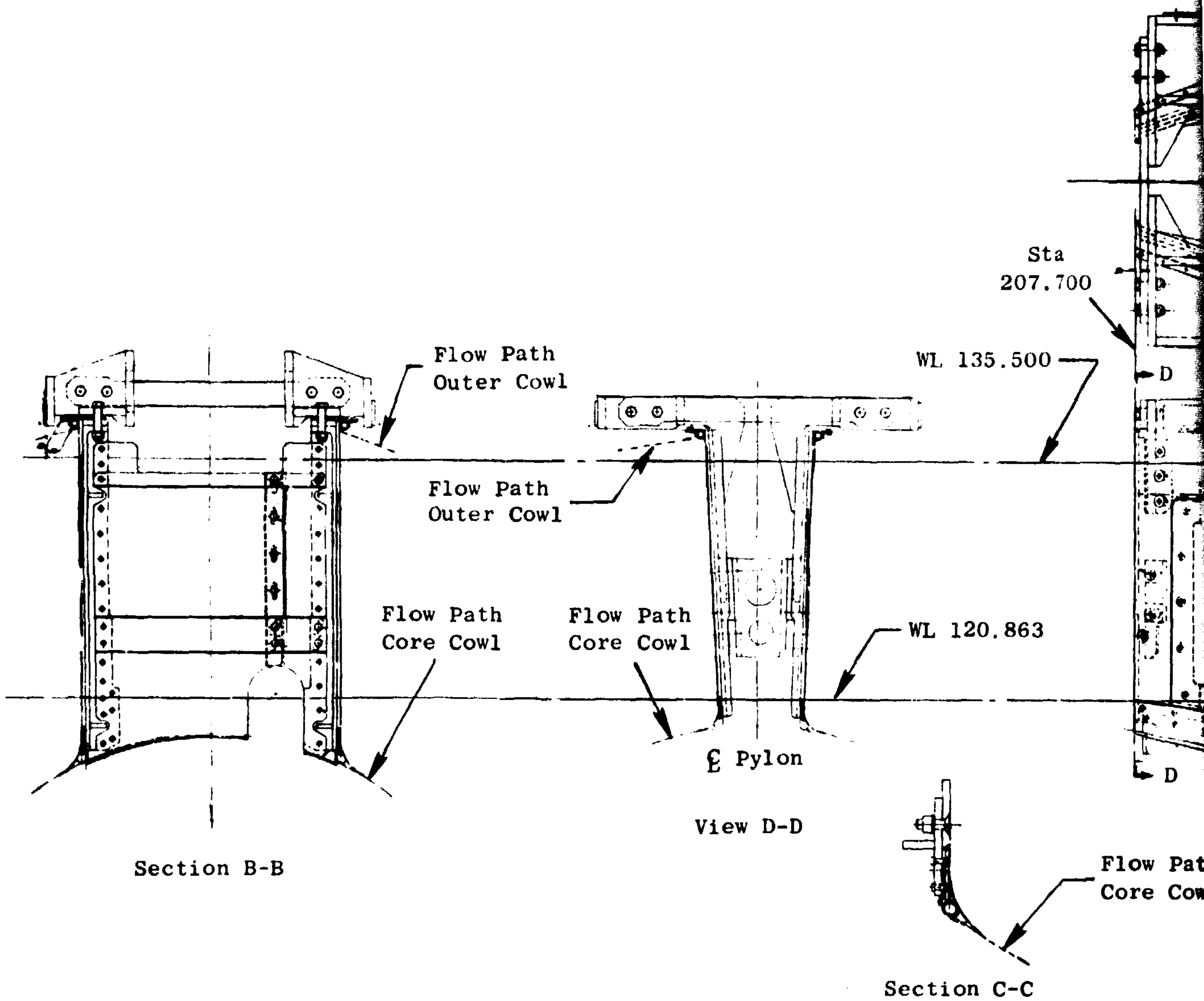


Figure 15. Forward Pylon Assembly and

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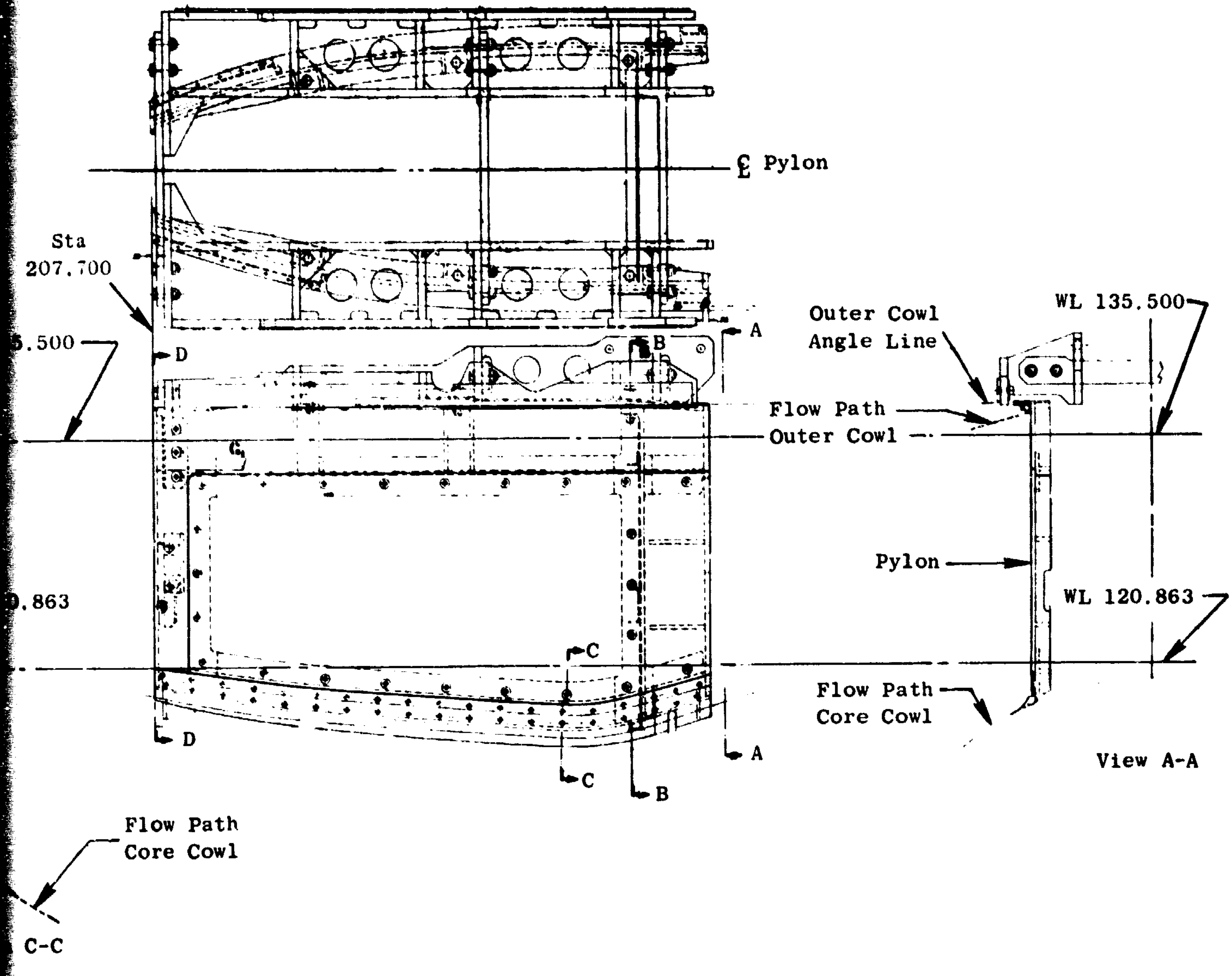

lon Assembly and Upper Support Structure.

hard face sheet for a perforated face sheet. All the materials used for the panels in the inlet and fan doors have 450° K (350° F) capability.

A typical SDOF acoustic panel cross section is shown in Figure 16, and a complete panel assembly is shown in Figure 17. All of the panels are processed from a tool simulating the flowpath. Face sheets are stretch formed to the proper contour to reduce residual stress between the face sheet and the core material after curing and to provide a smooth contour. The core material was chosen to be Hexcel aluminum Flex-core (5052/F40 with Hexabond adhesive on one side). The Flex-core design is preferred for its favorable contouring characteristics over standard honeycomb in double-curvature applications.

The inlet and fan door panels are fabricated in a single cure cycle. The faceplate is positioned in the tool with the Flex-core (Hexabond side against the faceplate). Three plies of NARMCO 3203 prepreg cloth are wrapped over the assembly with core splicing between core sections and edge fill around the edges. The entire assembly is cured under pressure.

The core door panels are fabricated by a similar procedure using different materials. The Flex-core for these panels will be procured without the Hexabond adhesive. The adhesive used between the faceplate and the Flex-core is Metalbond 328. This is a reticulating, unsupported film adhesive. The film adhesive is laid over the Flex-core and a heat gun is applied to reticulate the adhesive. (The heat causes the film adhesive to break between cells and to collect on the foil ridges). Utilization of a reticulating adhesive prevents plugging of the faceplate. The NARMCO 3203 prepreg is replaced with FERRO E293 prepreg, and one ply of Metalbond 329 supported film adhesive is added between the E293 and the Flex-core to improve the adhesive characteristics of this particular prepreg. (See Figures 18, 19, 20, and 21 for treatment definition number 1.)

(2) Bulk Absorber - Kevlar

The design and construction of these panels are shown in Figure 22. The panels are fabricated from SDOF tooling except for the Z section stiffeners which will require some contour forming. The bulk absorber material is style 1295 Kevlar 29 aramid 101.6 cm (40 in.) wide Type 973 felt in 1.27 cm (5 in.) thicknesses. Its density is controlled by compressing eight layers to the 2.54 cm (1 in.) depth of these panels.

The method of construction is identical to the bulk-absorber design used for the "C" Engine fan exhaust splitter used in the Quiet Engine Program. The faceplate is bonded and riveted to Z section stiffeners and then positioned in the existing panel tooling. The bulk absorber is cut and stacked in the available area before the aluminum backing plate is bonded and riveted to the Z section stiffeners. The adhesive used in the bonding process is EA 901/B1.

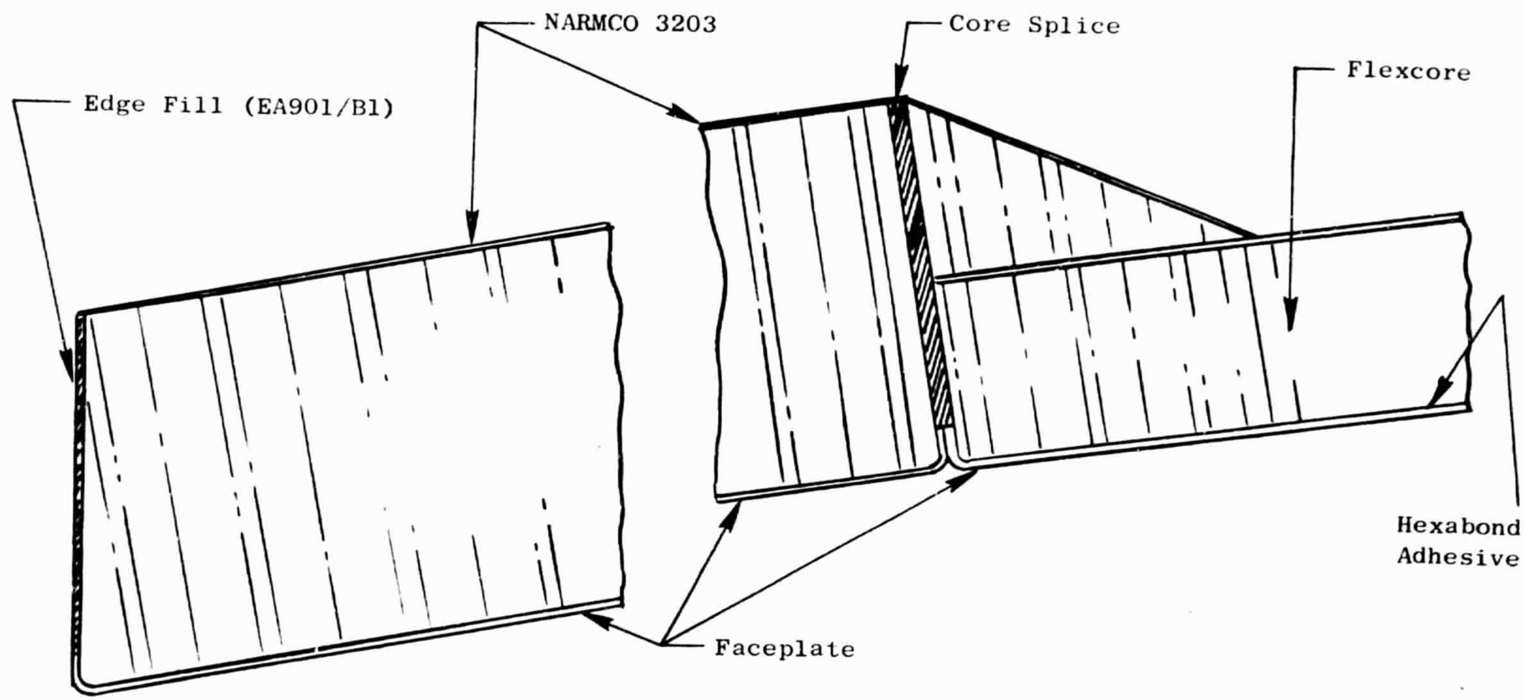

Figure 16. SDOF Acoustic Panel.

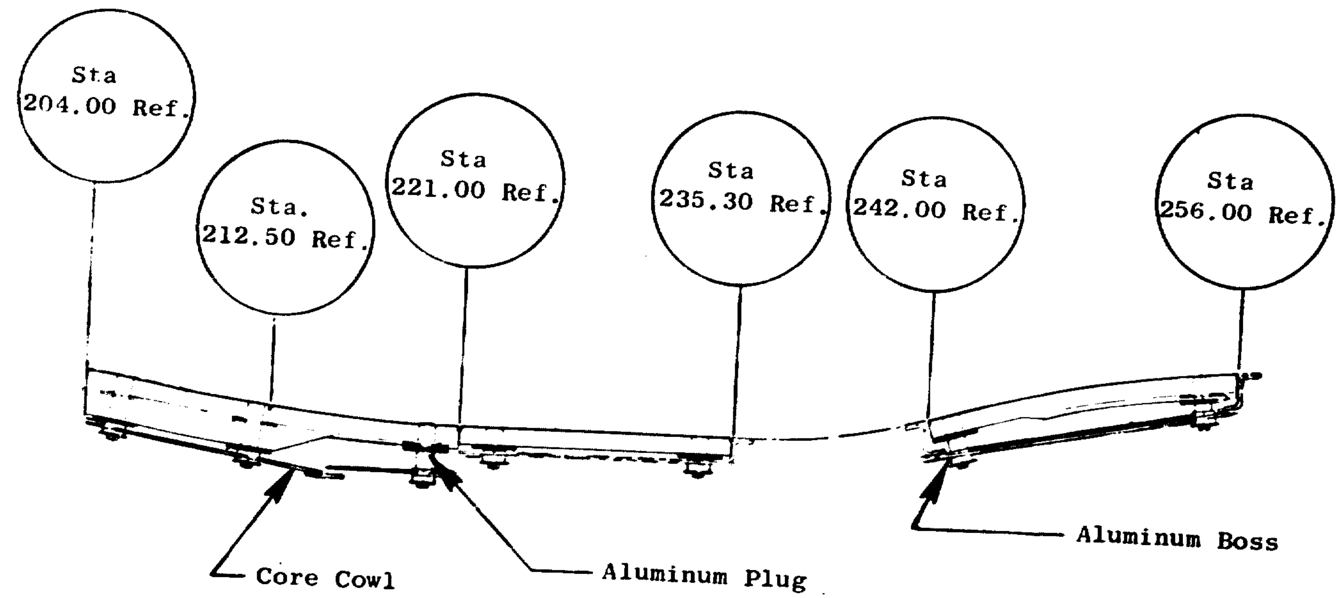

Figure 17. Typical Panel Attachment.

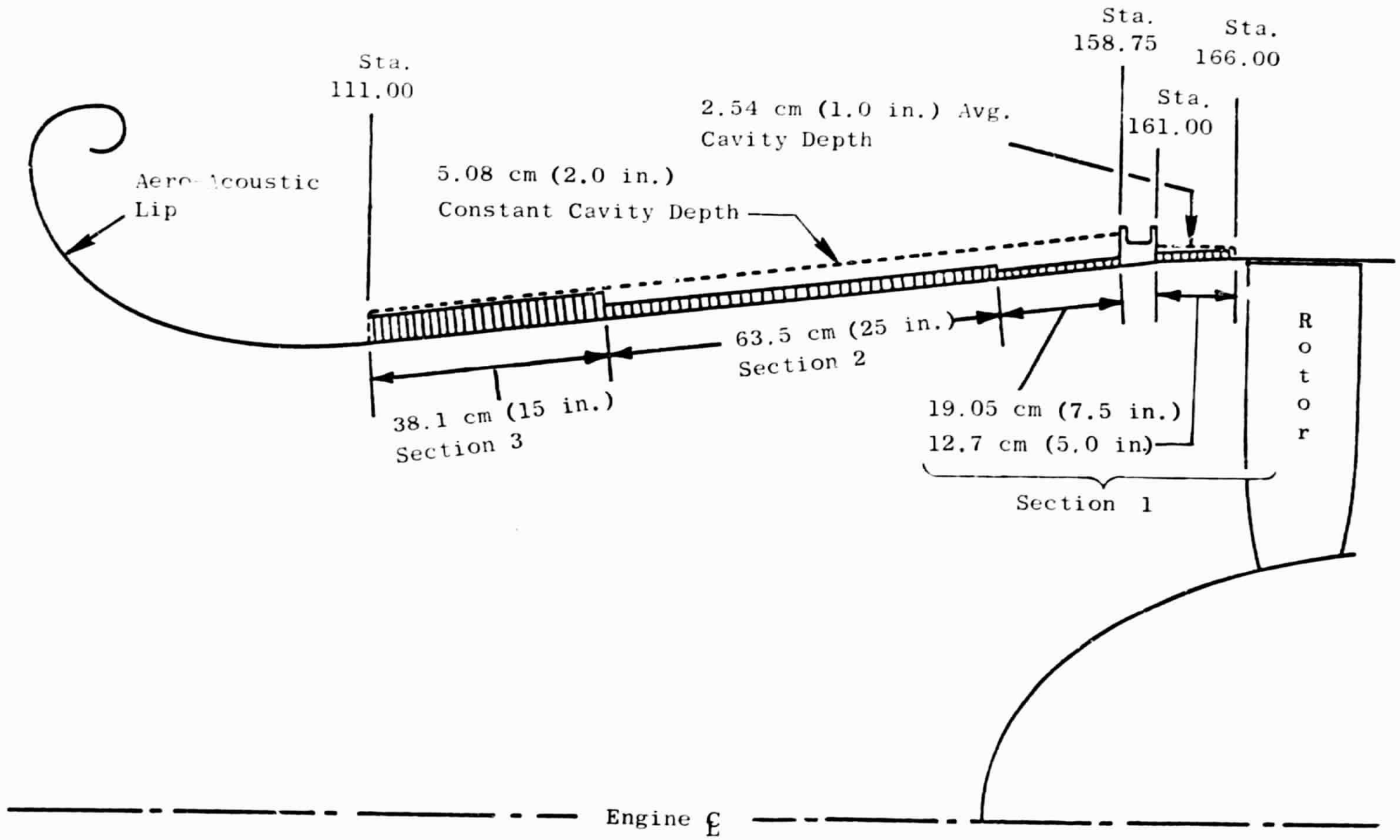

Figure 18. UTW Boiler Plate No. 1 Fan Inlet Treatment Design.

Section	Hole Size	Porosity	Cavity Depth	Faceplate Thickness
1	0.159 cm (0.0625 in.)	9.89%	1.27 cm (0.50 in.)	0.081 cm (0.032 in.)
2	0.159 cm (0.0625 in.)	9.89%	1.91 cm (0.75 in.)	0.081 cm (0.032 in.)
3	0.159 cm (0.0625 in.)	9.89%	3.81 cm (1.50 in.)	0.081 cm (0.032 in.)

Figure 19. Inlet No. 1 Treatment Design Details.

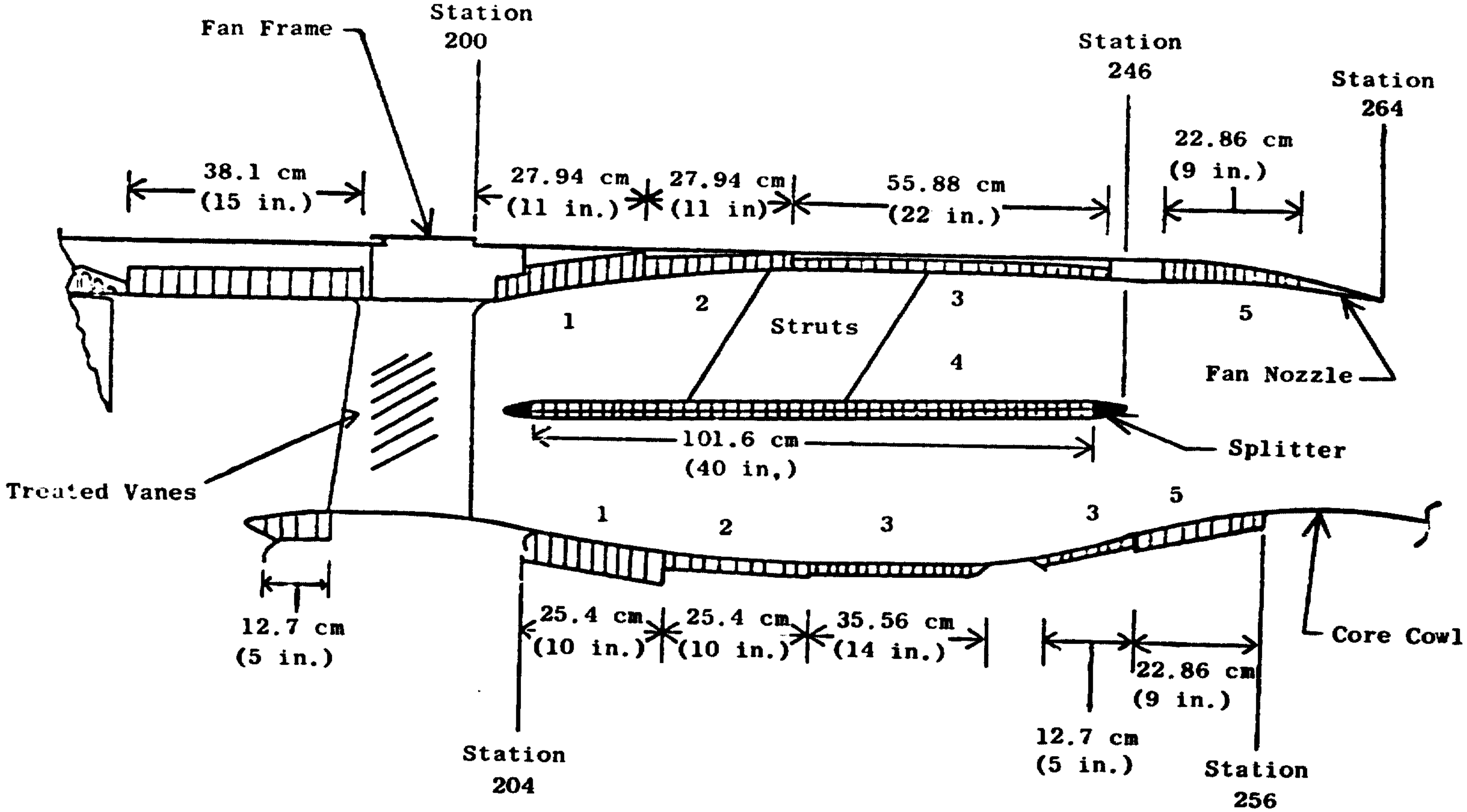

Figure 20. QCSEE UTW Boiler Plate No. 1 Fan Exhaust Treatment Configuration.

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Section	Depth	Porosity %	Hole Size	Face Sheet Thickness
1	5.08 cm (2.00 in.)	22.0	0.170 cm (0.067 in.)	0.102 cm (0.040 in.)
2	2.54 cm (1.00 in.)	15.5	0.170 cm (0.067 in.)	0.102 cm (0.040 in.)
3	1.91 cm (0.75 in.)	15.5	0.170 cm (0.067 in.)	0.102 cm (0.040 in.)
4	1.27 cm (0.50 in.)	11.5	0.198 cm (0.078 in.)	0.203 cm (0.080 in.)
5	2.54 cm (1.00 in.)	15.5	0.170 cm (0.067 in.)	0.102 cm (0.040 in.)

Figure 21. Fan Exhaust No. 1, Walls and Splitter.

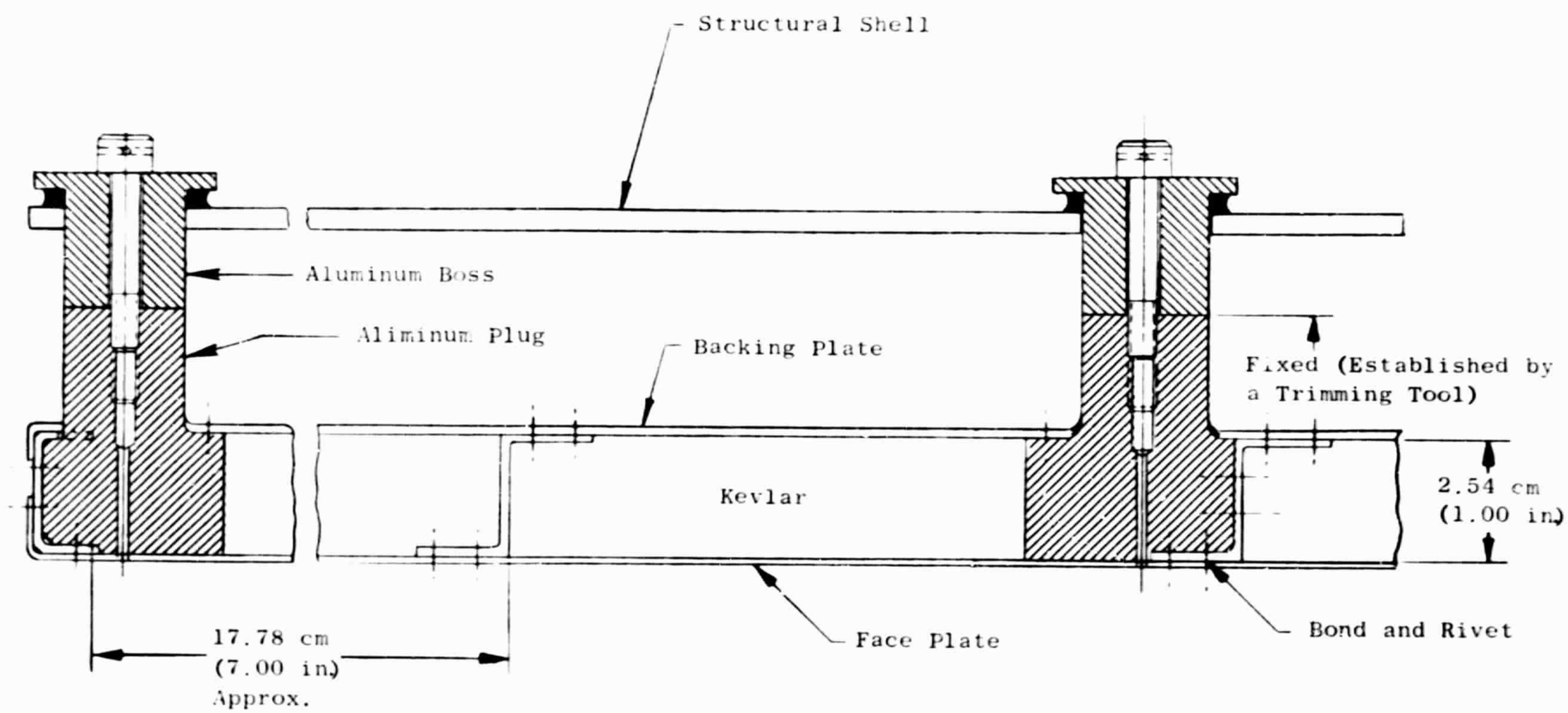

Figure 22. Bulk Absorber Panel.

(3) <u>Fasteners</u>

The method of attachment for all the panels is shown in Figure 17. The primary objective of this design is to provide a panel configuration that is reproducible in its interface even when the structural shell is not available for trial fit. The distance from the flowpath to the top of the plug is fixed. The aluminum boss that is attached (welded) to the structural casing is positioned at assembly by means of a trimming tool. The plugs in all future panels can then be matched to this fixed dimension. The following criteria were defined and implemented into this design.

1) The aluminum plug attachment:

   a) For SDOF and hard-wall panels; the plugs are bonded with EA 901/B1 to the perforated plate, Flex-core side walls, and then tied to the backing sheet with tree plies of wet lay-up.

   b) For bulk-absorber panels; the plugs are bonded with EA 901/B1 to the faceplate, Z section (drive rivets are also used), and the backing plate.

2) Threaded inserts are installed in the aluminum plugs.

3) Fastener positions will accommodate both bulk-absorber and SDOF panels.

4) The bolts are 1.27 cm (0.25 in.) and are spaced approximately 3.05 cm (12 in.) apart.

SECTION III

INSTRUMENTATION

A complete list of the instrumentation will not be presented here; however, it is important to note some of the design features that were implemented solely for instrumentation purposes.

In general, all provisions for aerodynamic and acoustic probes and rakes have the same design concept throughout the nacelle. The mounting bosses are firmly attached to the structural casings, and blank-off pads are provided to fill the opening, when the instrumentation is not in use, to provide a smooth flowpath. The hard-wall panels have provisions for a complete set of aerodynamic and acoustic instrumentation; however, only aerodynamic and acoustic probes can be used when the acoustic panels are installed.

The hybrid inlet utilizes four equally spaced 2.54 cm (1 in.) wide axial ribs. They form a continuous nonremovable flow line for wall-static and kulite instrumentation. This design feature provides a nonremovable instrumentation capability for different panel configurations. The inlet also contains mounting provisions for the single strut that supports the slip-ring assembly.

The fan exhaust splitter has a removable section in the leading edge that provides a slot for an acoustic probe to traverse the entire flow annulus. When the probe is not in use the slotted leading-edge piece is replaced by a full nose piece (Figure 23). Holes are also provided in the leading edge to accept traversing cobra and dynamic-pressure probes.

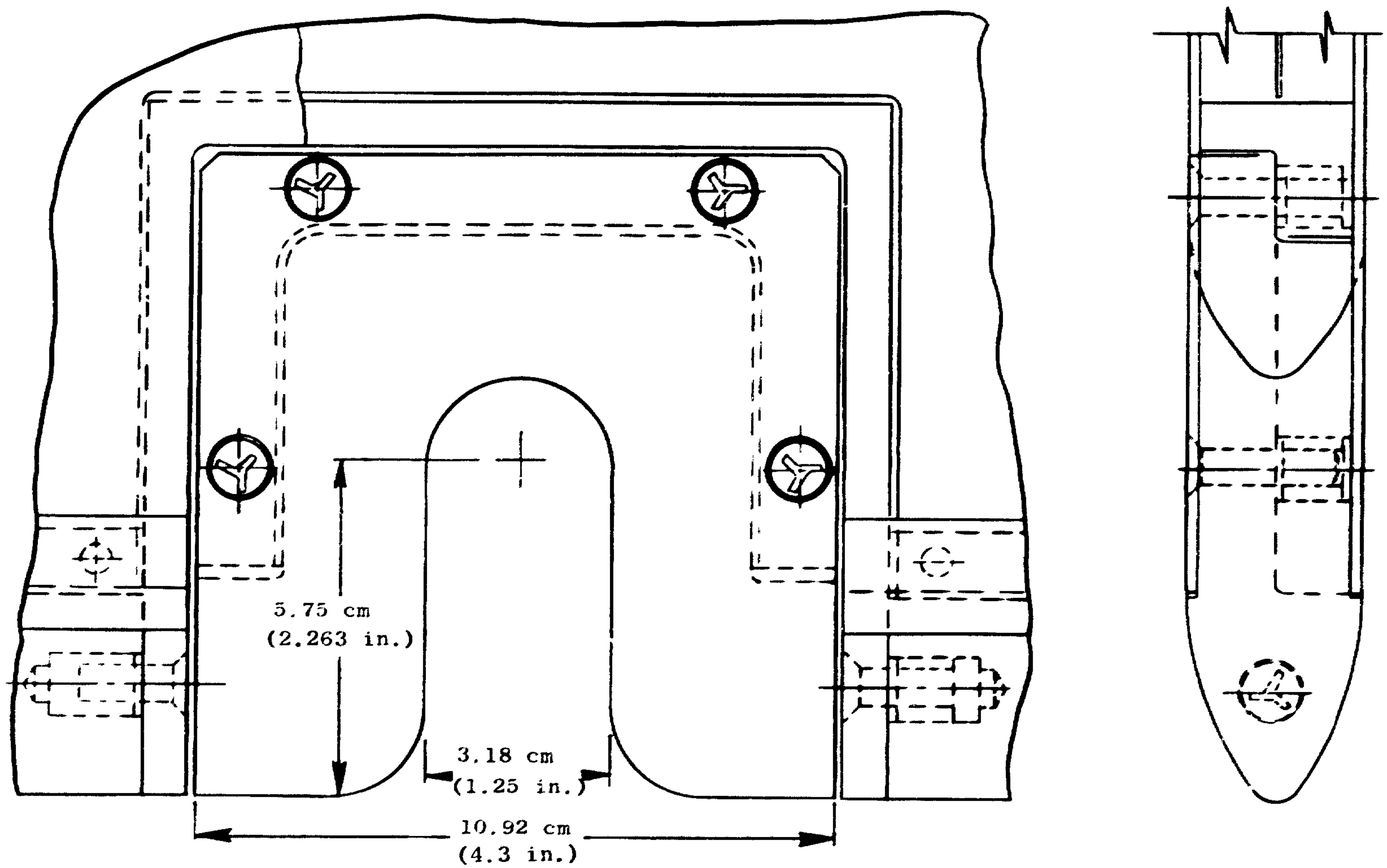

Figure 23. Splitter Instrumentation Leading Edge Provision.

SECTION IV

NACELLE INSTALLATION

The assembly of the bellmouth, four-ring splitter, and the hybrid-inlet configurations is identical, and similar to all other decoupled inlet systems tested at Peebles. Relative positioning is accomplished at final assembly on the test stand by line drilling the facility mounting bars with the structural support rings provided on each inlet configuration.

The installation of the fan cowl doors, pylon, and core cowl doors (because of several close-tolerance interfaces) is a complex and difficult task. This entire assembly was fabricated to fit a close-tolerance tooling mandrel at GE-Mojave. The installation procedure is to use the assembly as an integral unit and, by fine tuning the adjustments at the facility mount interface, match the centerline of the system and the engine. Once this is accomplished, the assembly is pinned to the mounts and the installation process is complete.

A detailed description of the installation process follows: the UTW engine and dolly assembly are lifted to the facility mount structure, and the forward mount pins, thrust links, and turbine mount links are installed. The dolly system is then removed from the engine (Figure 24). The pylon upper support structure and forward assembly (pylon sidewalls), including the fan cowl hinge structure, is loosely attached to the engine mount with predrilled holes that were calculated to be on a common centerline (Figure 25). The fan cowl doors are attached to the hinge and closed. Adjustment is provided for the pylon upper-support-structure-to-mount interface. This shimming capability fits the fan cowl doors to the fan frame and aligns the fan cowl doors and engine centerline to achieve a smooth flowpath transition (Figure 26). The fan cowl doors are removed for convenient access to the core door installation. The core cowl door hinge and apron structure is loosely attached to the forward pylon assembly. The hinge/apron structure floats relative to the pylon assembly. The core cowl doors are attached to the hinge and fitted to the fan frame core extension ring. This attachment couples the core cowl doors to the fan frame. To open the doors, a system of tapered pins must be incorporated to accurately locate the doors (Figure 27). After all fits are found to be acceptable, the upper pylon support structure is pinned to the facility mount assembly; and, the facility telescoping support bars are installed on the fan cowl door, completing the installation (Figure 28). Engine accessibility is shown in Figure 29. The doors are located and locked open mechanically. The fan cowl doors are held in place with the telescoping beams pinned in an intermediate position, and the core cowl doors are held open with a spreader bar at two hinge locations.

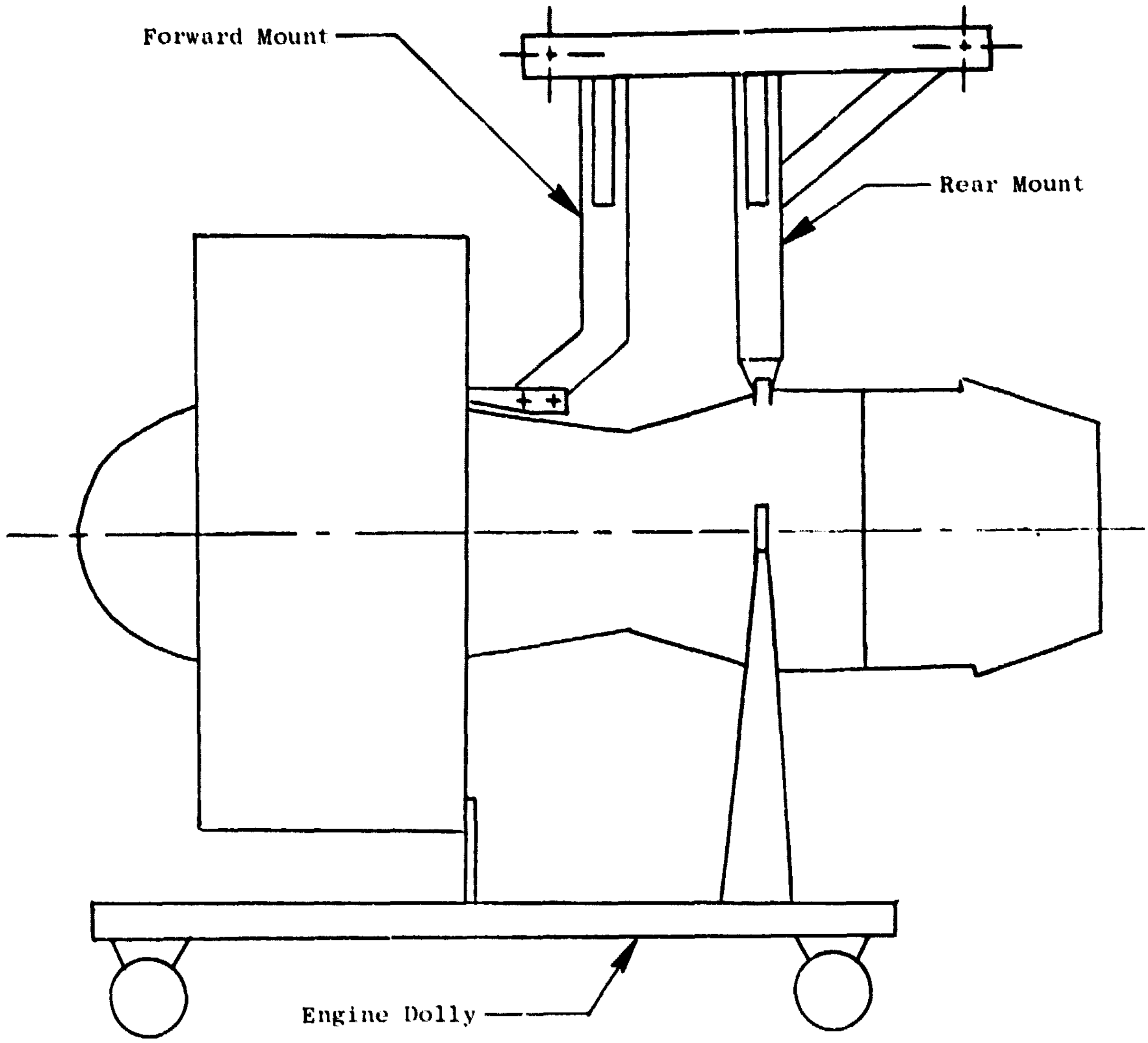

Figure 24. UTW Engine and Dolly Lifted to Facility Mount.

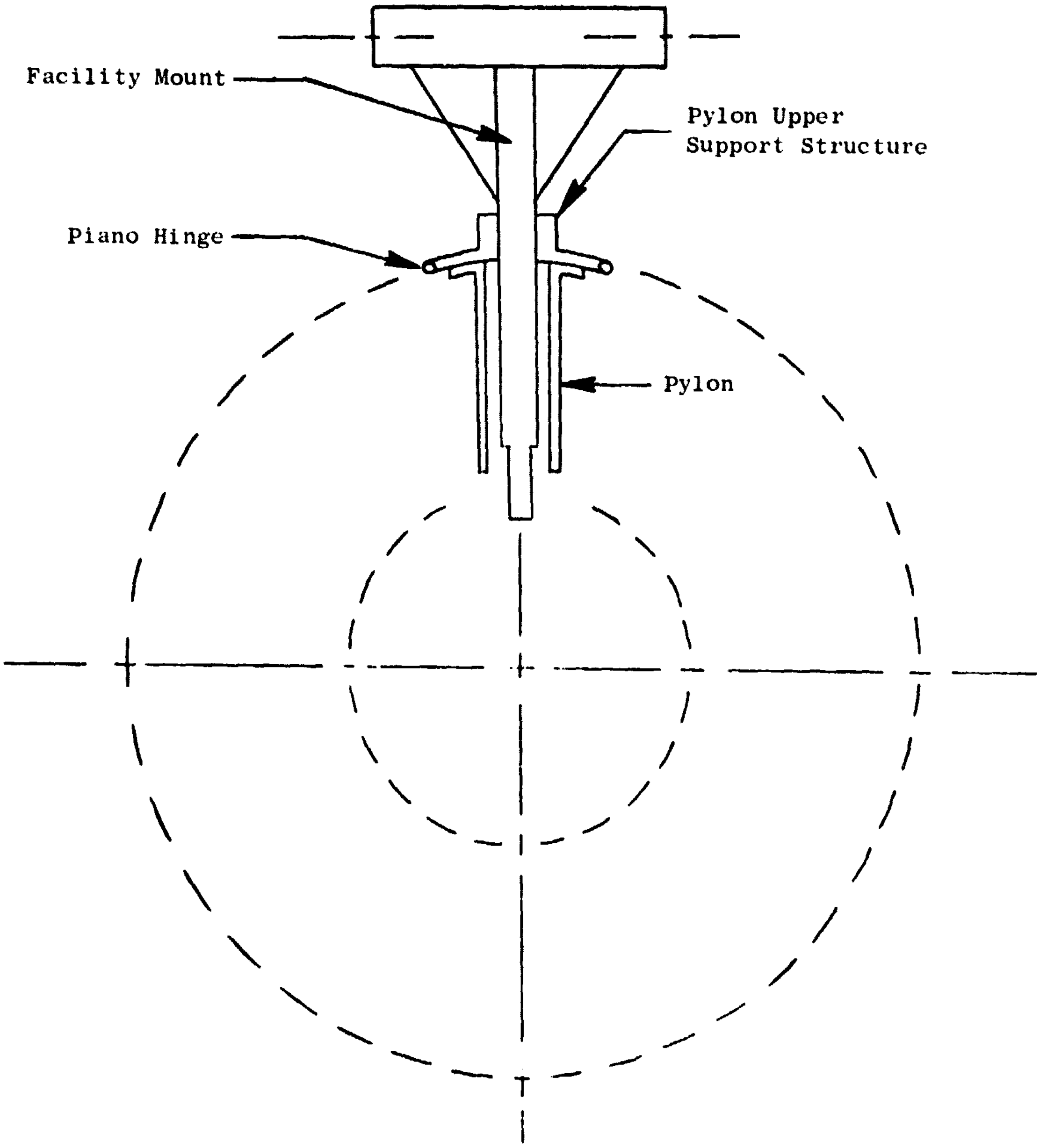

Figure 25. Fan Cowl Hinge Structure Loosely Attached to Engine Mount.

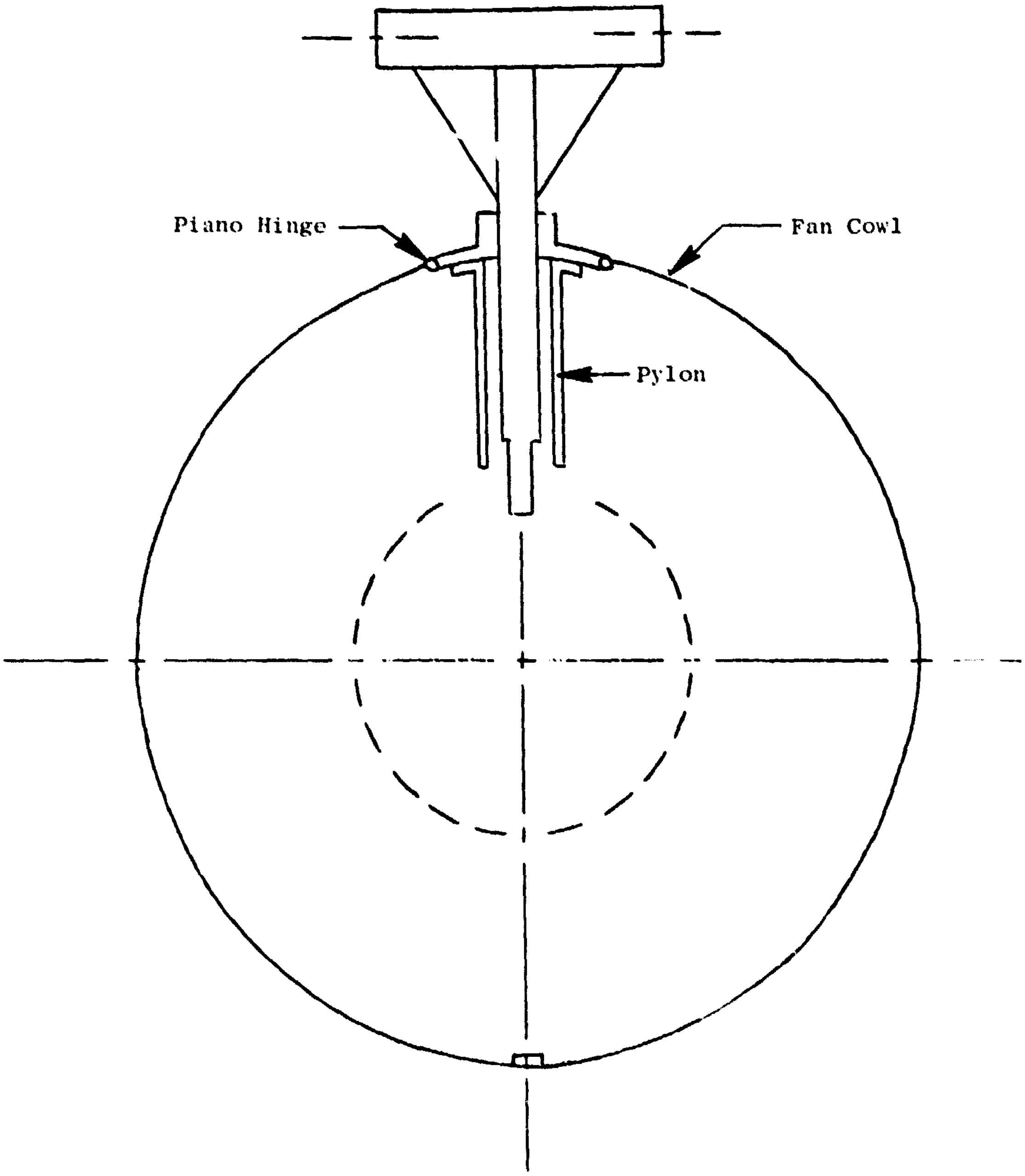

Figure 26. Fan Cowl Doors Attached to Hinge, Fitted to Fan Frame.

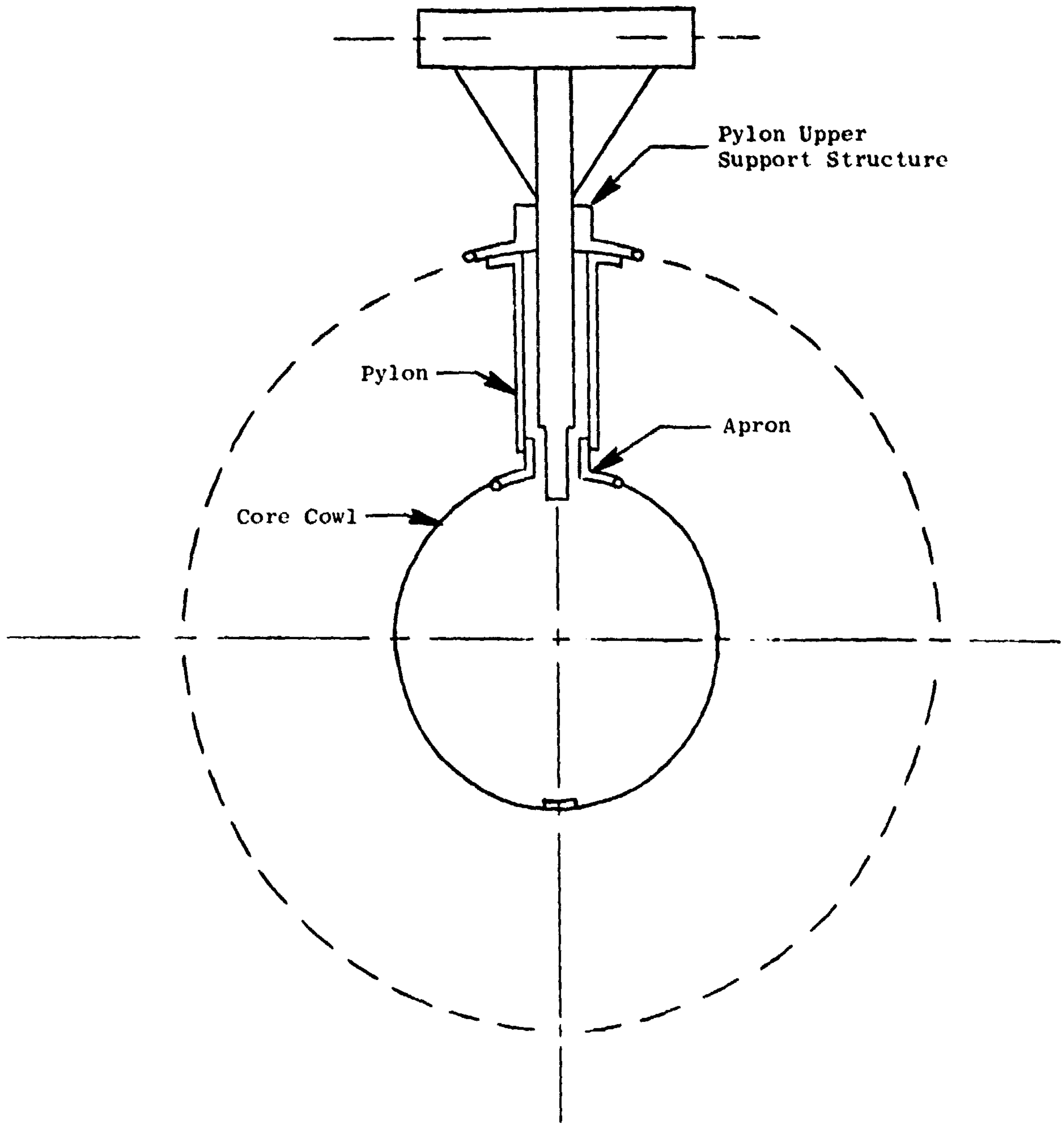

Figure 27. Core Cowl Doors Attached to Hinge and Fitted to Core Ring-Fan Frame.

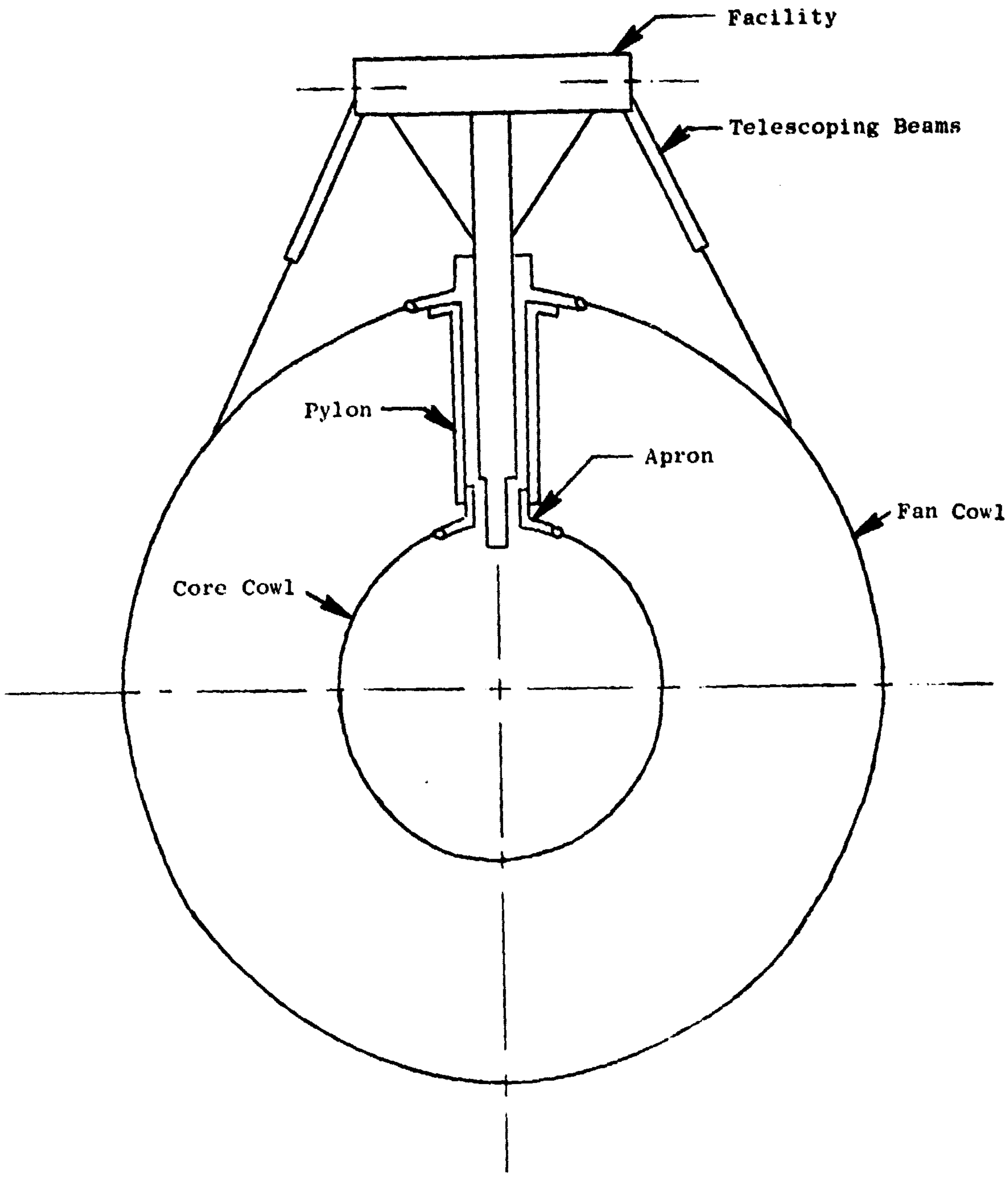

Figure 28. Fan Doors Installed; Lateral Steady Rods Installed.

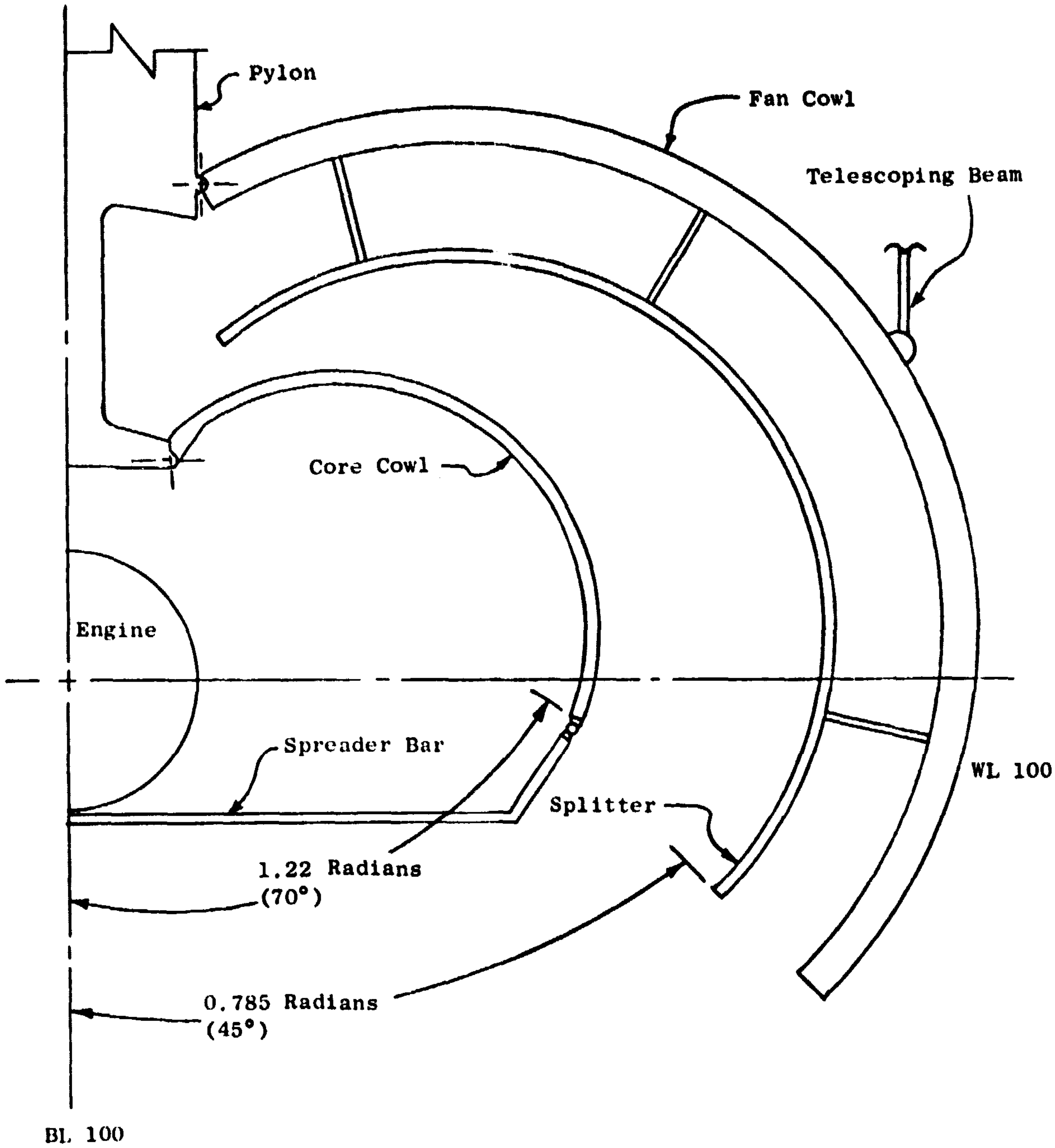

Figure 29. Cowl Opening Diagram.

SECTION V

ANALYSIS

The following is a summary of the strength, stiffness, and continuity of the main structural subassemblies of the UTW boiler plate nacelle. Since the basic philosophy was to design a high-strength, fatigue-resistant structure, these components are all considerably overstrength. This concept is standard practice for test hardware of this type.

A. SPLITTER/STRUT SYSTEM

Steady-state design of the splitter struts proved that the stresses did not intersect the Goodman-limit curve below an A = 1 line [σ_{ss} < 68.95 N/cm^2 (100 psi)]. This criterion assures that the allowable vibratory stress will always be greater than the steady-state stress, a condition which experience dictates to be desirable. Stress and vibratory analysis was performed using the GE "Twisted Blade" program.

Aeromechanically, the cross section of the airfoils was designed such that the first flexural and first torsional modes would not be excited by blade passing frequencies in the 60-110 percent speed range. The proposed design is such that the strut end fixities are built-in to simulate a fixed-fixed condition. The advantage of the structurally stiff strut supports is in the significantly increased level of the first flexural and torsional frequencies above the unstable one- and two-per-rev (integral multiple of rotor speed) excitation range (Figure 30).

An area of major concern on test engines is that of system critical frequency. Normal design practice dictates the avoidance of all rotor criticals up to at least 110 percent physical speed. Resonances associated with stationary components, such as the splitter/strut system, are mechanically tuned to fall out of the critical range between 60-110 percent physical speed, where high-energy excitation could be encountered for an extended time period. The analytical model used the strut stiffness parameters to achieve acceptable system vibration characteristics. The splitter was assumed to be a rigid body, due to its integral sandwich construction.

A system mode is one in which vibratory coupling occurs between the struts and the splitter. The interplay between these two components resulted in the selection of stainless steel struts and an aluminum splitter. The advantage of the final configuration is the increased frequency level of the lowest-energy system modes. These frequency levels provide the ability to avoid rotor blade-passing resonance in the one- and two-per-rev spectrum, while maintaining a resonable margin below the higher excitation energies that can occur at or above the 60 percent speed ranges (See Figure 31).

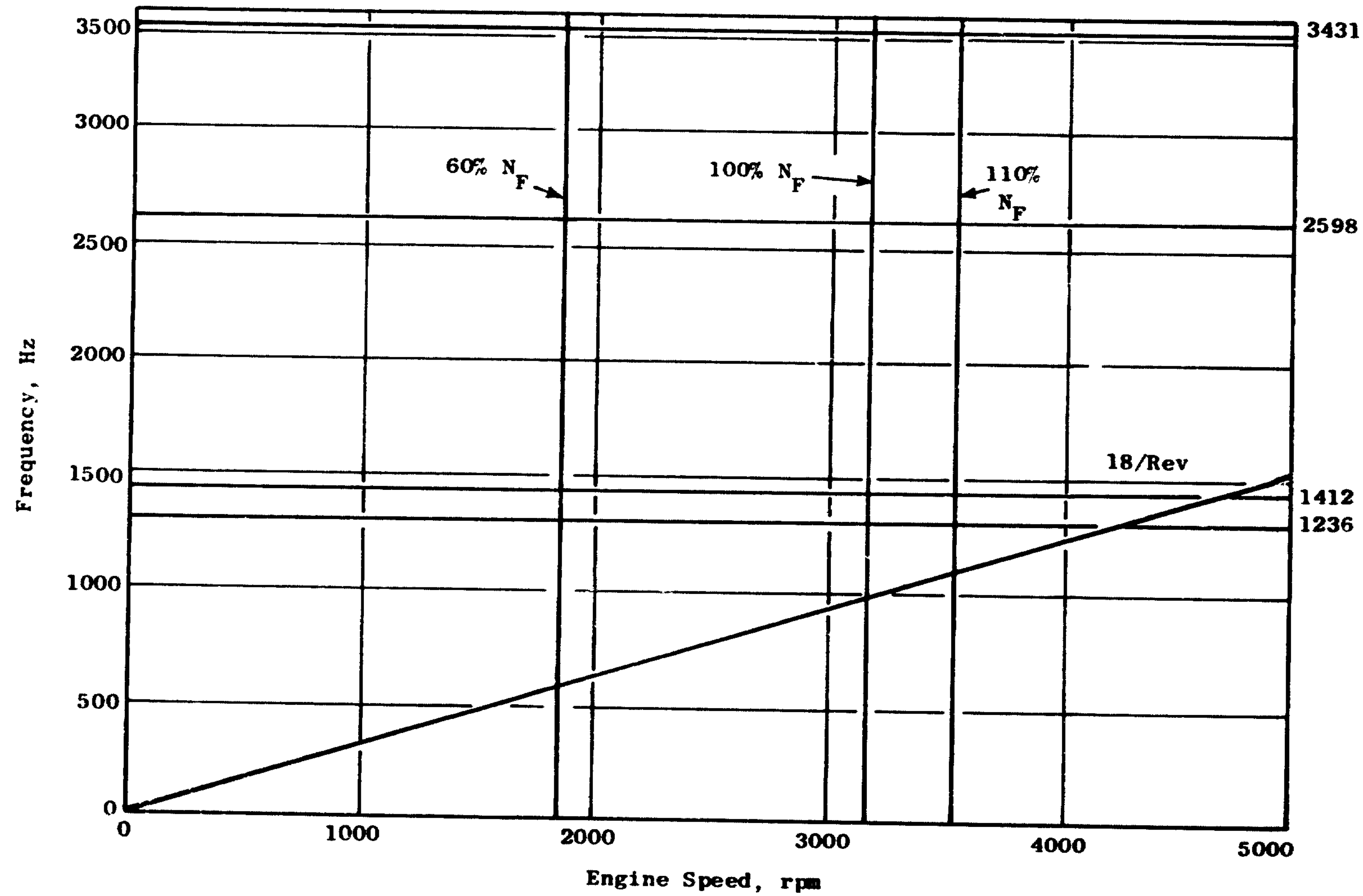

Figure 30. UTW Splitter Struts, Critical Speed Diagram.

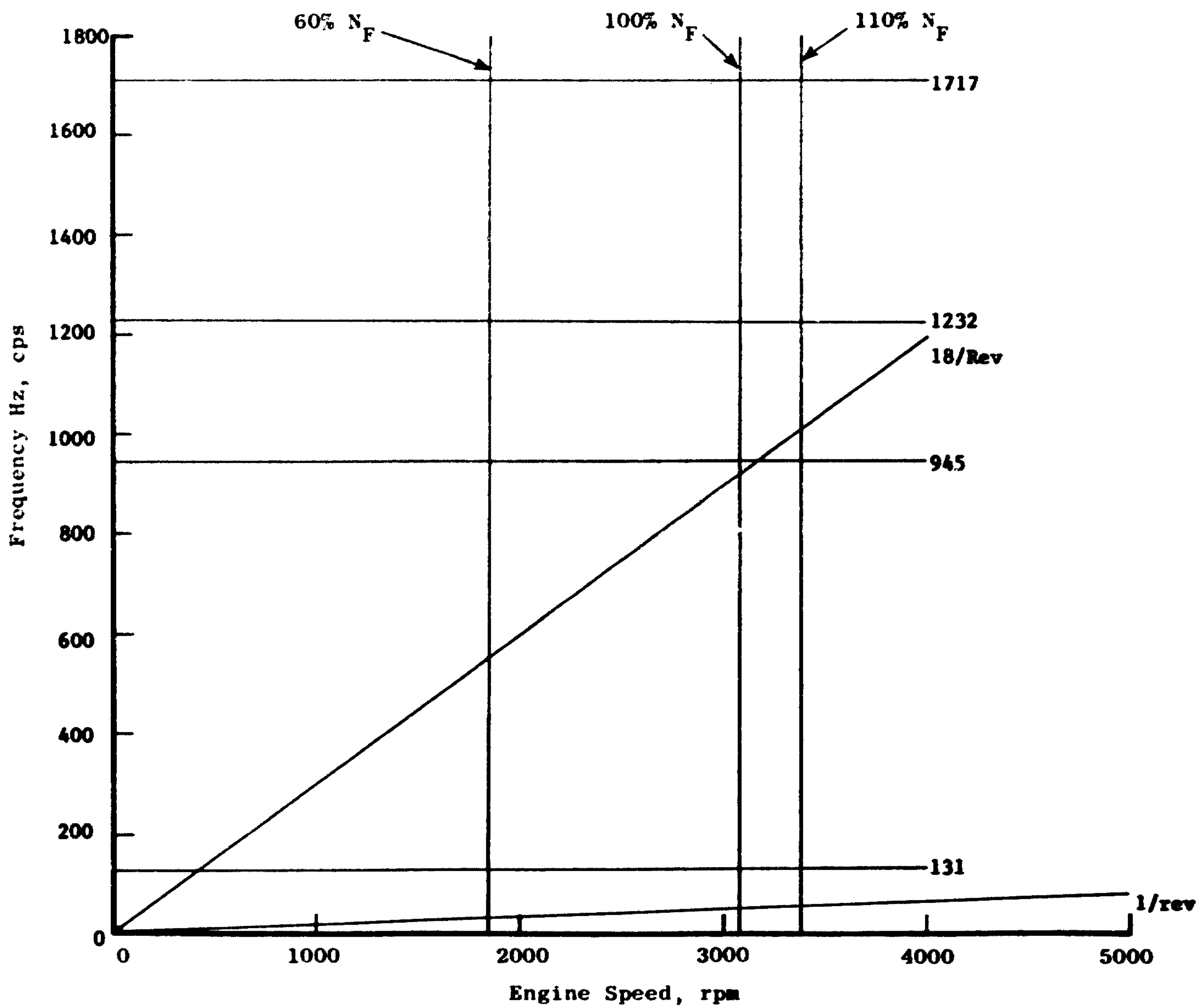

Figure 31. QCSEE Splitter with Steel Struts, Critical Speed Diagram.

B. CORE COWL COOLING

The core cowl will employ a cooling system utilizing pressurized air in conjunction with radiation shields and bleed air from the fan duct. This system will adequately cool the cowl area and ensure a safe operating environment for the epoxy resins that will be used in the construction of the acoustic and hard-wall panels.

The bleed air from the fan duct is only used in the cavity forward of the engine fire wall, and it has been incorporated into the boiler plate nacelle in order to obtain cooling information for the composite core cowl. The pressurized air cooling system is divided into forward and aft circuits with individual airflow controls (Figure 32). Cooling is accomplished by distributing the air around the plenum chamber and using the gap between the structural shell and the radiation shield to meter the cooling flow. The cooling flow requirements were established by allowing a maximum structural shell skin temperature of 394° K (250° F) in the region of removable panels. This temperature can be maintained with cooling flows of 0.091 kg/sec (0.2 lb/sec) in the forward chamber and 0.227 kg/sec (0.5 lb/sec) in the aft chamber. Thermocouples on the structural shell will continuously monitor the actual skin temperature to verify the calculations. The system provides airflow adjustments to match system needs, permits cooling after shutdown to control soak temperature, and provides a positive cooling technique during reverse operation.

(See Figure 33 for the final calculated temperature distribution of the structural shell during engine operation.)

C. INLET

The loading conditions used to establish the design features of the inlet assembly are:

1) 22,240 N (5000 lb) forward load on the aeroacoustic lip, based on aerodynamic calculation.

2) 3.45 N/cm^2 (5 psi) crushing pressure at the throat due to the Mach number (0.79).

Define:

$$\text{Factor of Safety (F.S.)} = \frac{\text{Allowable Stress}}{\text{Actual Stress}}$$

(1) Aeroacoustic Lip

The critical buckling-pressure analysis for honeycomb sandwich structures calculated a pressure of 20.6 N/cm^2 (29.9 psi). This gives a F.S. value of 6.0 for the lip.

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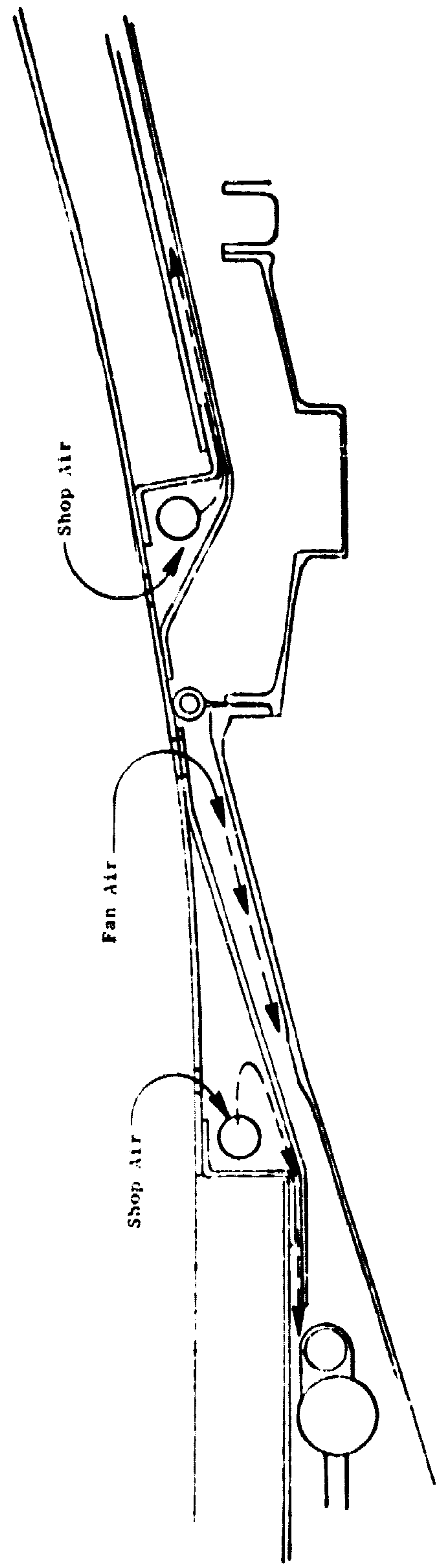


Figure 32. Cooling System Schematic.

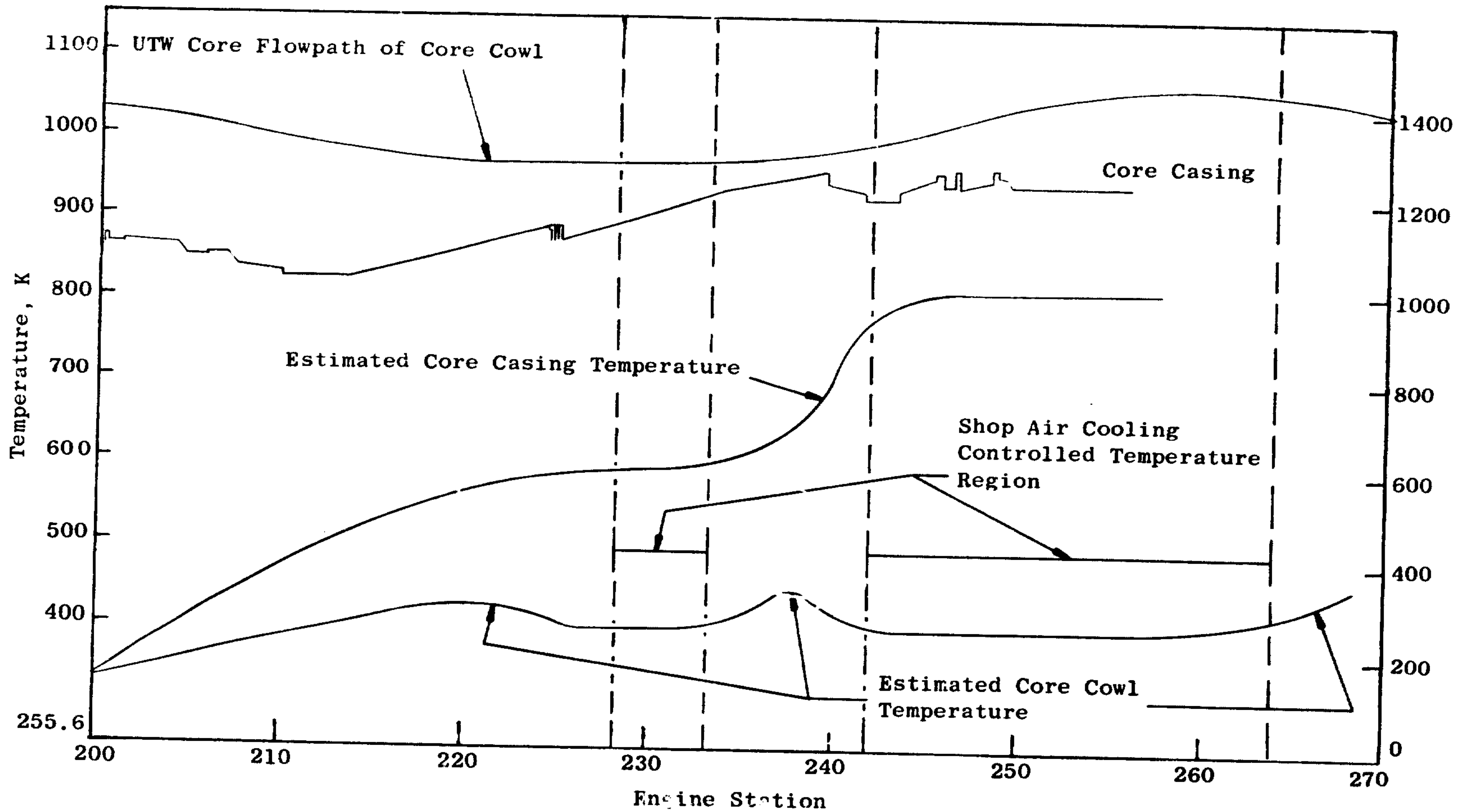


Figure 33. Calculated Core Cowl Temperature For Shop Air Cooling.

(2) Housing

A sampling of the results for the inlet housing quickly shows the ruggedness of this component.

Shell analysis at Station 142.8:

1) Hoop Stress = 499.9 N/cm^2 (725) psi

2) Longitudinal Stress = 250.3 N/cm^2 (363 psi)

Rivet loads at the 3.14 radian (180°) splice joint:

1) 823 N (185 lb)/fastener or F.S. = 4.7

Ring Analysis at Station 125.0:

1) Critical buckling pressure = 39.6 N/cm^2 (57.5 psi) or F.S. = 2.05

2) Ring Bending stress = 372.3 N/cm^2 (540 psi)

3) Ring hoop stress = 482.7 N/cm^2 (300 psi)

Failure analysis of skin between rings:

1) Critical allowable buckling pressure for a typical shell of this structure is 10.1 kN/cm^2 (14.6 ksi) or F.S. = 13.3

Because the loads on the fan and core doors are of the same small magnitude as the above loads, they will not be presented in the report. (Note: Δp for the inlet is 3.44 N/cm^2 (5 psi) and for the exhaust is 1.38 N/cm^2 (2 psi) for the forward mode and 2.41 N/cm^2 (3.5 psi) for reverse UTW and forward OTW).

D. FAN DOOR LATCHES AND HINGES

The loading conditions were derived from the static pressure distributions in the take-off and reverse modes for both QCSEE Engines.

1) 15568 N (3500 lb) aft load on the flare nozzle for static test

2) 1.38 N/cm^2 (2 psi) for hoop tension UTW and 2.41 N/cm^2 (3.5 psi) for OTW

3) 2.41 N/cm^2 (3.5 psi) compression for the UTW in the reverse mode

(1) Latches

Due to an internal pressure of 2.41 N/cm^2 (3.5 psi), the latch reactions are 25,042 N (5630 lb). This gives a F.S. = 2.1.

(2) Hinges

The hinges are designed to react side and vertical loads and normal-to-the-plane moments (looking down the engine centerline) for the fan doors. They are designed to function equally well during all pressure conditions.

The load on the hinge due to the pressure force is 288.8 N/cm (165 lb/in.). The load from the flare nozzle is 472.5 N/cm (270 lb/in.). These shears can be superimposed to find the total loading condition of 761.3 N/cm (435 lb/in.) at one end of the hinge, with a linear distribution producing a -183.8 N/cm (-105 lb/in.) at the other end. For a 0.95 cm (3/8 in.) hinge pin, the maximum shear stress has a F.S. = 19. The most severe condition is in the 0.635 cm (1/4 in.) shear bolts that mount the hinge assembly. They have a F.S. = 2.44 which is still quite adequate.

E. CORE COWL DOORS

The loading conditions were derived from the static pressure distribution for both QCSEE engines, where the most severe delta pressure was found to be 2.41 N/cm^2 (3.5 psi).

(1) Hinges

Combined loading conditions vary because each hinge configuration is slightly different. Hoop tension and compression loads for the core cowl door and apron assembly were derived from the QCSEE static pressure distributions for both engines. The resulting delta pressure of 2.41 N/cm^2 (3.5 psi) was applied for all hinge configurations. The calculated load on each hinge is 5564.4 N (1251 lb) due to that pressure. The minimum F.S. for shear tear-out of one of the hinge designs was found to be 11.8, which is very conservative.

(2) Latches

The allowable load for each latch is 8896 N (2000 lb). Since the latch loads are the same value as the hinge loads, the F.S. for the latch design is 1.6.

PART II

CORE EXHAUST NOZZLE

SECTION I

INTRODUCTION

This section covers the design of the nonflight-weight core exhaust nozzle, which (in the demonstrator engine) is interchangeable in the UTW and OTW engine configurations.

The QCSEE UTW engine is shown schematically in Figure 34. The core exhaust nozzle was designed to suppress both high-frequency, turbine and low-frequency, combustor noise to meet the overall engine objective of:

95 EPNdB 152.4 m (500 ft) sideline, during takoff and approach

100 PNdB 152.4 m (500 ft) sideline, during maximum reverse thrust

To meet the design objectives, acoustically treated subassemblies, that are interchangeable with similar hard-wall subassemblies, were designed to provide the baseline- and suppressed-noise levels. These components also are interchangeable between the OTW and UTW engines.

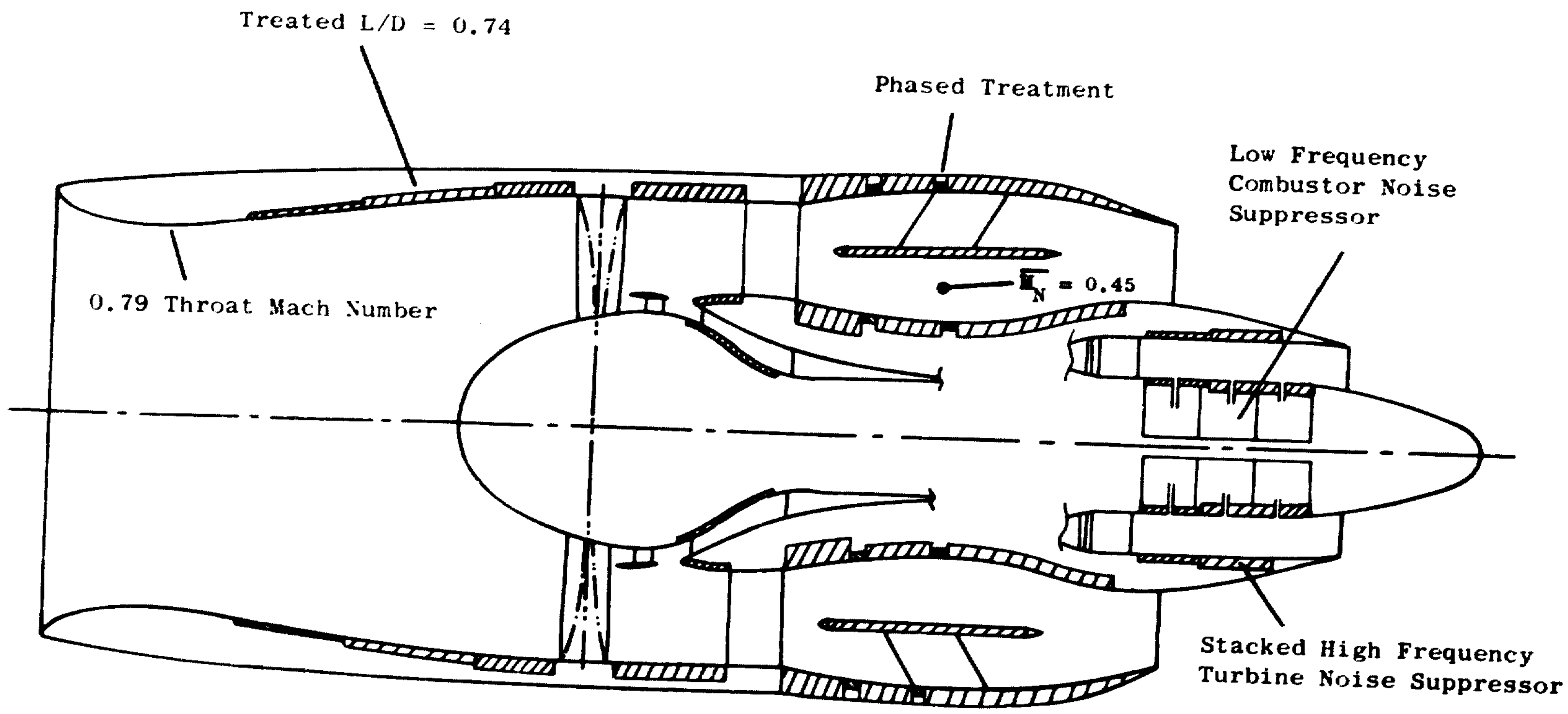


Figure 34. QCSEE UTW Engine.

SECTION II

NOZZLE DESCRIPTION

The acoustically treated core exhaust nozzle, shown in Figure 35, is a fixed-area nozzle with a separate but intechangeable outer cowl that is bolted to the aft core and can be trimmed for a ±5% core nozzle area adjustment.

A radial service-line strut is located at the bottom centerline of the core exhaust nozzle to provide aerodynamic fairing over the oil-in, oil drain, seal drain, and piston balance air lines that (in the experimental engines) are routed through the core nozzle to the sump. The strut assembly is designed so that the strut and service lines need not be disassembled to remove the centerbody or outer duct. This feature was desirable to allow the interchangeability of a hard-wall and acoustically treated subassembly without disconnecting the service lines.

The strut has a fish-mouth seal that engages the centerbody as it is pushed forward to be bolted to the turbine-frame flange. The outer duct is bolted to the outer turbine-frame flange and the strut to form the outer seal. The strut assembly is also bolted to the outer turbine-frame flange, but still has a slip joint between the strut and centerbody to accommodate radial-differential, thermal expansion between the strut and the inner and outer accoustic treatments during transient flight conditions.

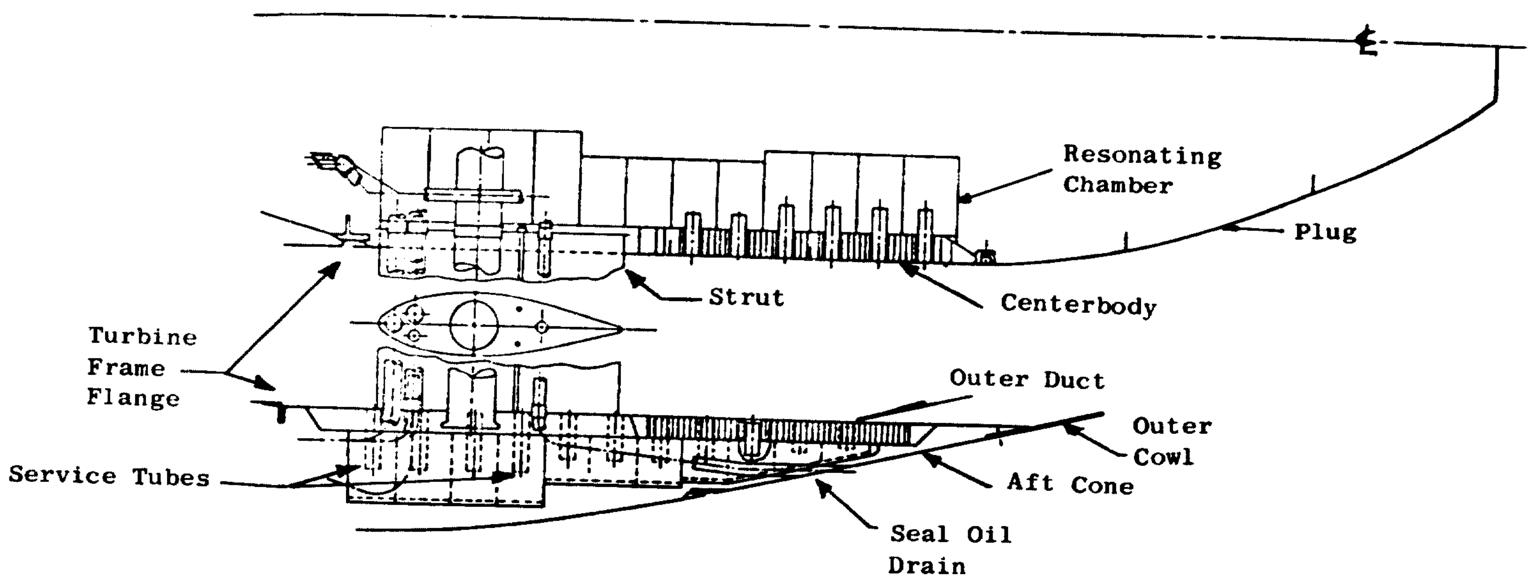


Figure 35. QCSEE Core Exhaust Nozzle.

SECTION III

DESIGN REQUIREMENTS

The nonflight-weight core exhaust nozzle was designed to meet an experimental engine life cycle that includes fan mapping at elevated pressure ratios as specified in the QCSEE Preliminary Technical Requirements, November 1, 1974.

SECTION IV

DESIGN CONSIDERATIONS

A. COMMON OTW AND UTW FLOWPATHS

Several iterations were required before a common core exhaust nozzle flowpath was found for the UTW and OTW engines. The outer flowpath has straight-line coordinates which totally eliminated double-curvature surfaces, thus minimizing tooling and forming costs in fabrication of the prototype nozzle.

B. SUBASSEMBLY INTERCHANGEABILITY

Maximum interchangeability and commonality of parts was required because of the limited hardware procurement funding. The hardware procurement flowsheet for the UTW and OTW core exhaust nozzle is shown in Figure 36. Only one set of acoustic treatment panels and one set of hard-wall treatment panels were procured for use on the OTW and UTW test program.

Two sets of struts, nozzle cones, and centerbody plugs were procured so that both the OTW and UTW engines could be tested simultaneously, one with the acoustic treatment and the other with the hard-wall treatment.

C. ISOLATION OF THE SANDWICH CYLINDER

The inner and outer sandwich cylinder required isolation from the resonating chambers assembly because of the severe differential thermal expansion in the nozzle during start-up.

D. NOZZLE AREA ADJUSTMENT

The fixed-area nozzle required ±5% area adjustment to cover the range of uncertainty in the predicted performance of the engine core components.

E. LOW-COST SHEET METAL DESIGN

The large number of parts required to build the resonating chamber assembly required a cost effectiveness study to reduce or minimize forming which would require high tooling charges for a limited one-of-a-kind procurement.

F. MATERIAL SELECTION

The cost of the basic sheet metal material is a small fraction of the total cost of fabricating a one-of-a-kind product. Inconel 625 was selected as the sheet material because of its moderate thermal expansion coefficient and its good forming and welding properties.

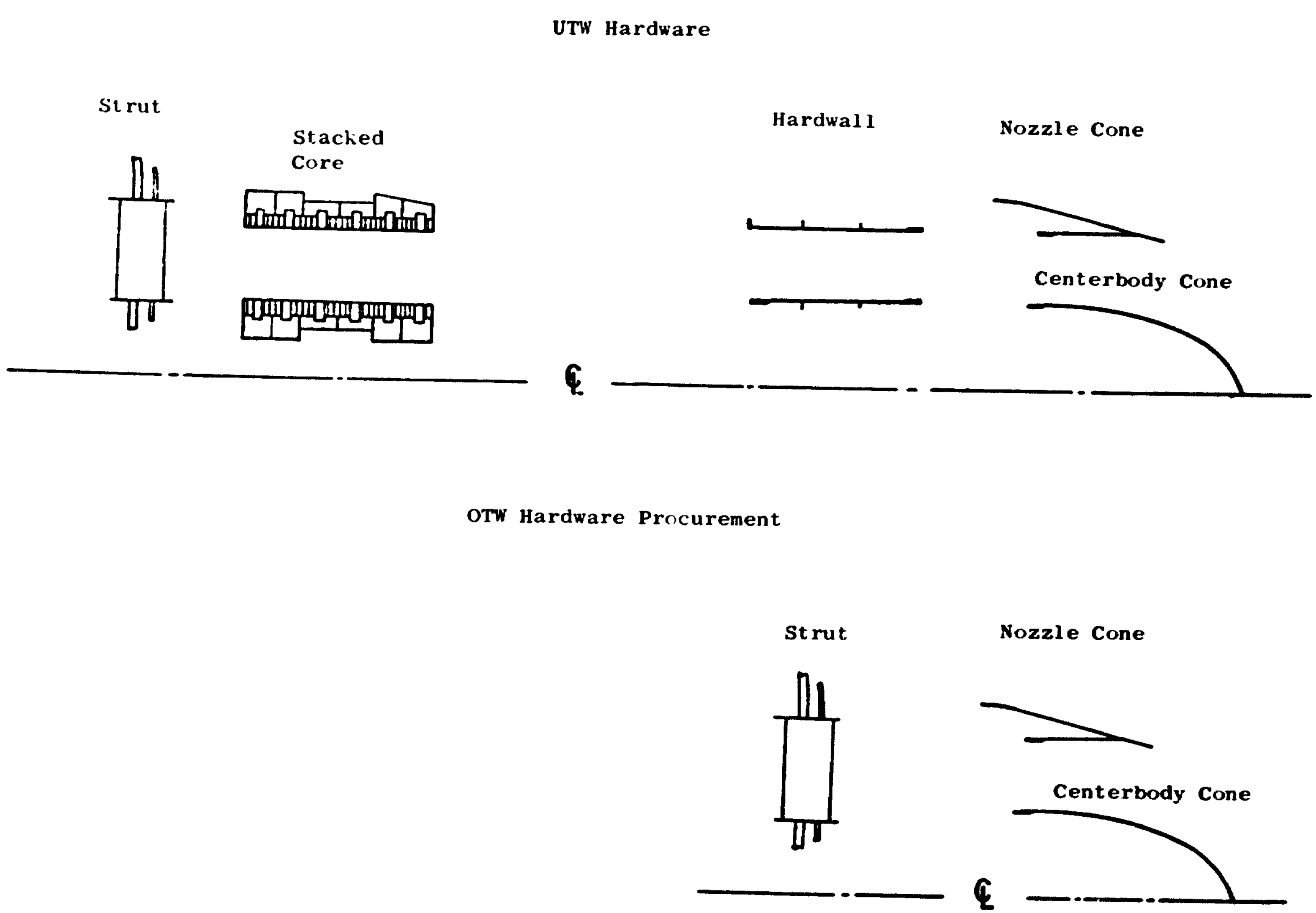


Figure 36. QCSEE UTW and OTW Core Nozzle Hardware Procurement.

SECTION V

MATERIAL SELECTION

Inconel 625 and 321 SS were considered for fabricating the core exhaust nozzle. Inconel 625 was selected for all components except the outer nozzle cowl which is made of 321 SS. The outer cowl operates at a lower temperature than the other major components and does not have a differential thermal-expansion problem.

Inconel 625 was selected for the hot core exhaust nozzle components for the following reasons:

- The coefficient of thermal expansion of Inconel 625 closely matches the Inconel 718 turbine-frame flange, to which the core exhaust nozzle is bolted.
- Inconel 625 minimizes the low cycle thermal and mechanical fatigue problem at the nozzle exit, where the cool fan air merges with the hot core gas.
- The complexity of the acoustic-treatment geometry, severe thermal gradients, and stress concentration favored the use of Inconel 625 for better low cycle fatigue life.
- The weldability of Inconel 625, although comparable with 321 SS is preferred for repair welds.

SECTION VI

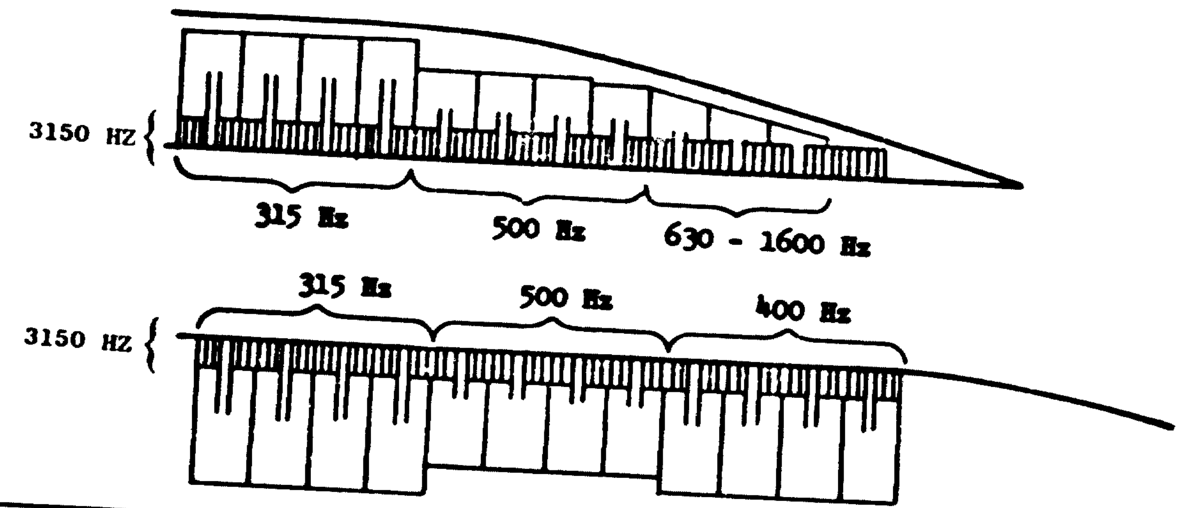
ACOUSTIC TREATMENT DESIGN

The stacked core acoustic treatment design for both the centerbody and outer duct are similar in concept, as shown in Figure 37. The high-frequency, turbine noise is suppressed by the sandwich cylinder that is fabricated by welding a metal honeycomb core to the face sheets. The face sheet on the flowpath side is perforated for communication between the flowpath gases and the noise-suppression sandwich cells. The lower-frequency, combustor-noise impulses enter the resonating chamber through radial tubes that penetrate the sandwich cylinders and project into the resonating chambers. The specifications for the acoustic treatment and the frequencies for which the resonating chambers were designed are given in Figure 37.

The use of acoustic treatment for noise suppression in hot-gas-flow applications, such as the QCSEE duty cycle shown in Figure 38, result in severe thermal-expansion problems. During transient conditions, such as engine start-up, the thin face sheets on the flowpath side rapidly approach the gas temperature, while the backside face sheet lags behind; as has been observed in two-dimensional, hot-gas tests using similar acoustic-sandwich material.

The thermal resistance of the honeycomb sandwich panel can be calculated from equations given in NASA TN D-171. A typical exit gas-temperature rise in the CFM56 engine core nozzle is shown in Figure 39. The CFM56 and the QCSEE engines use the F101 engine core. A typical turbine exit gas profile is shown in Figure 40. The temperatures of the flowpath face sheet and the backside face sheet (as a function of time) are shown in Figure 41. For a 1.91 cm (0.75 in.) thick sandwich, a maximum ΔT of 375° K (675° F) was calculated at 90 seconds from start-up (ΔT then decreases as the engine approaches steady state).

In the example shown in Figure 42, the thermal stress in the face sheet for a ΔT of 392° K (705° F) results in a nominal stress of 60.7 kN/cm^2 (88 ksi). For face sheets with perforations and large-diameter tube holes (as in the present acoustic-treatment design), the stress concentration factor in the face sheet (where a small perforation intersects the outer boundary of the hole) results in a notched-hole, stress-concentration factor that is equal to the stress-concentration factor of the hole times the stress-concentration factor for the notch. The combined stress-concentration factor for the notched hole is equal to four times the nominal stress in a biaxial stress field and nine times the nominal stress in a uniaxial stress field. The resulting stress concentration times the high calculated nominal stresses in the face sheet would severely limit its low cycle fatigue life, and the sandwich cylinder could not be relied upon as a load-carrying structure.



		Combustor						Turbine
		Inner Wall			Outer Wall			Both Walls
Tuning Frequency, Hz		315	400	500	315	500	630 - 1600	3150
Neck Length, (Faceplate Thick.)	cm (in.)	6.99 (2.75)	5.72 (2.25)	4.45 (1.75)	6.99 (2.75)	4.45 (1.75)	3.56 - 2.54 (1.4) - (1.0)	0.08128 (0.032)
Cavity Depth,	cm (in.)	10.2 (4.0)	8.89 (3.5)	7.62 (3.0)	7.62 (3.0)	4.32 (1.7) & 5.08 (2.0)	4.06 - 0.51 (1.6) - (0.2)	1.905 (0.75)
Porosity, %		10	10	10	7	7	7	10
Treatment Length,	cm	20.32 (8.0)	20.32 (8.0)	20.32 (8.0)	20.32 (8.0)	15.24 (6.0) & 5.08 (2.0)	20.32 (8.0)	60.96 (24.0)
Hole Diameter,	cm (in.)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	0.1575 (0.062)

Figure 37. Treatment Definitions.

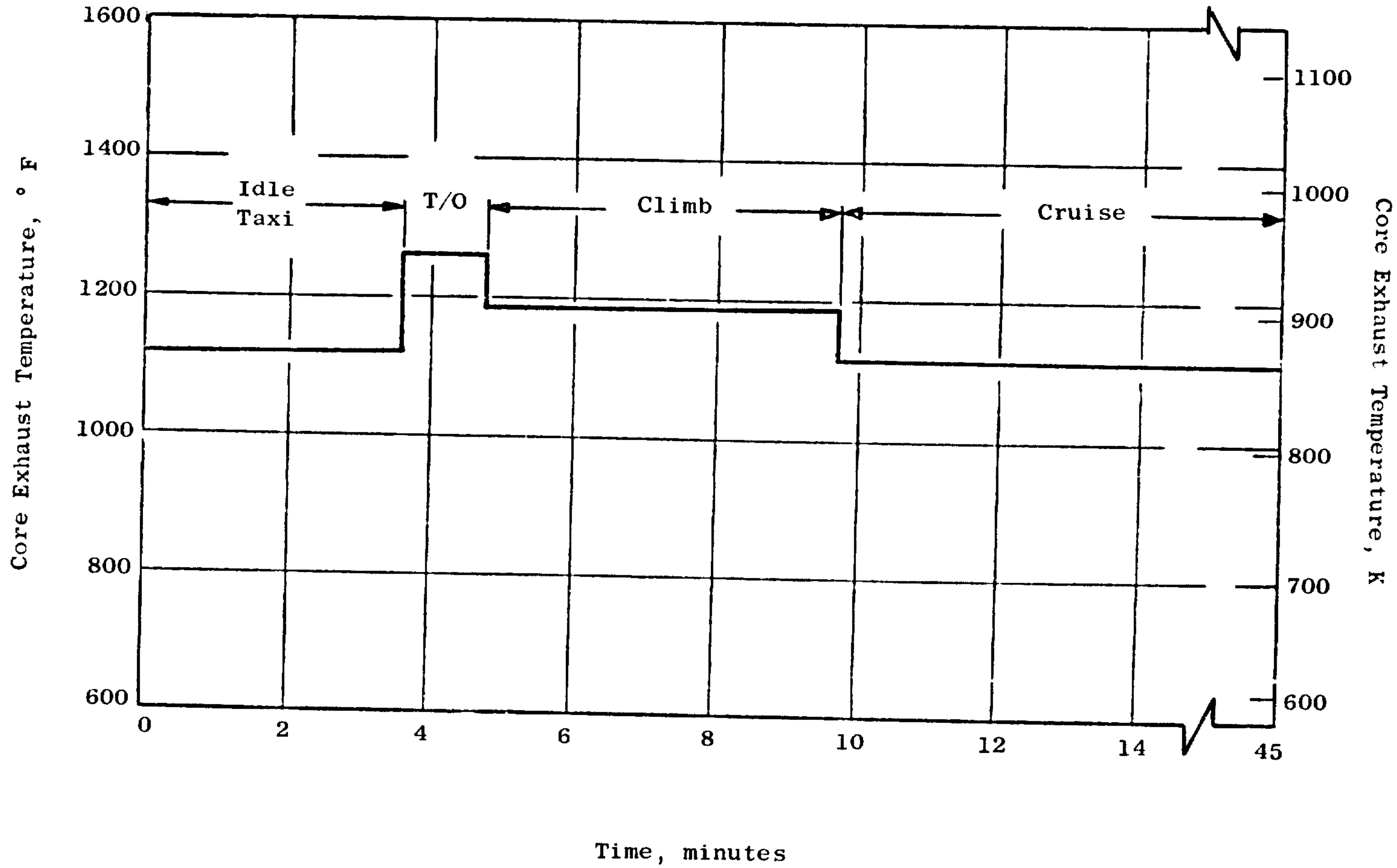


Figure 38. QCSEE Duty Cycle.

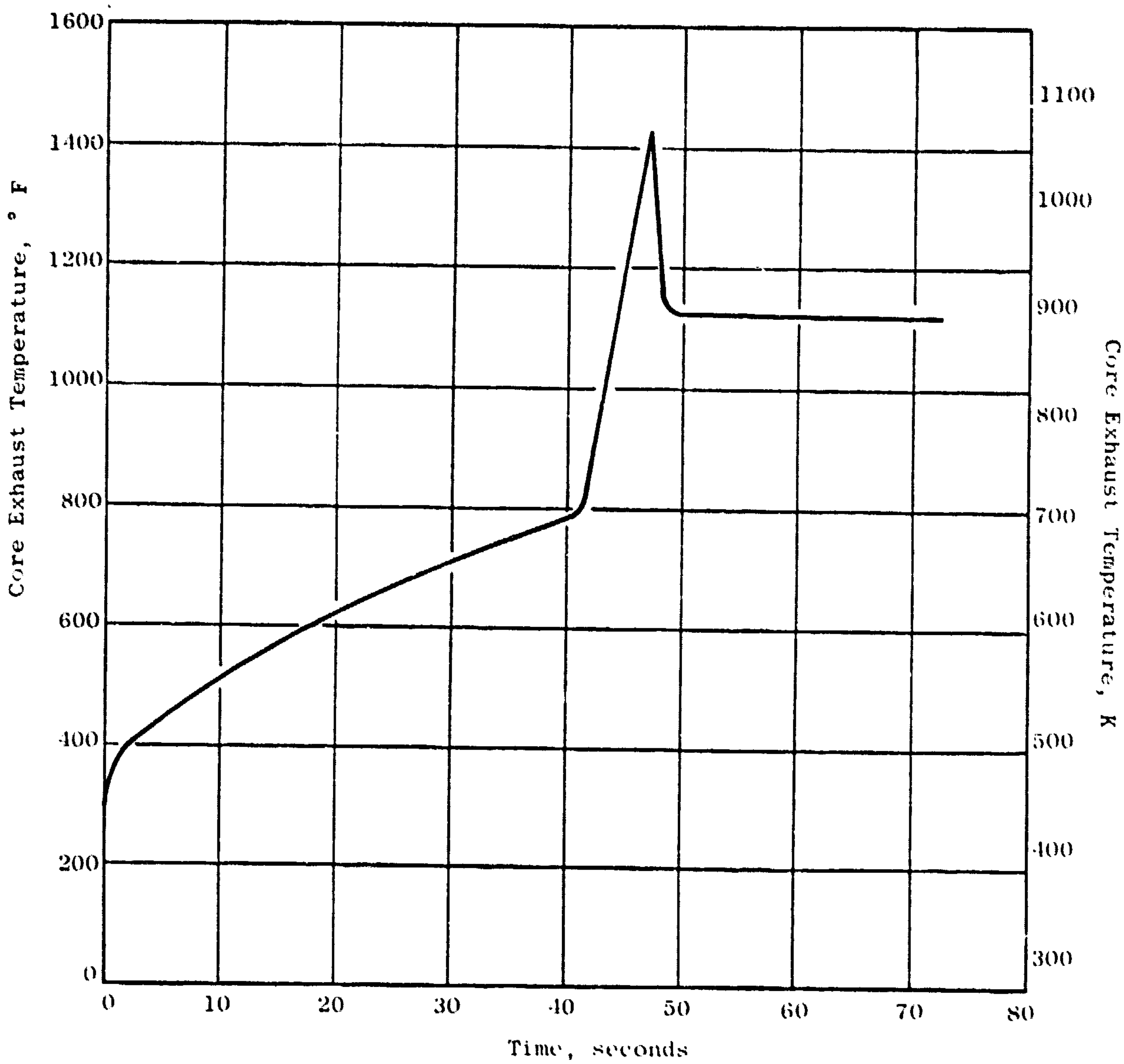


Figure 39. CFM-56 Typical Start-Up.

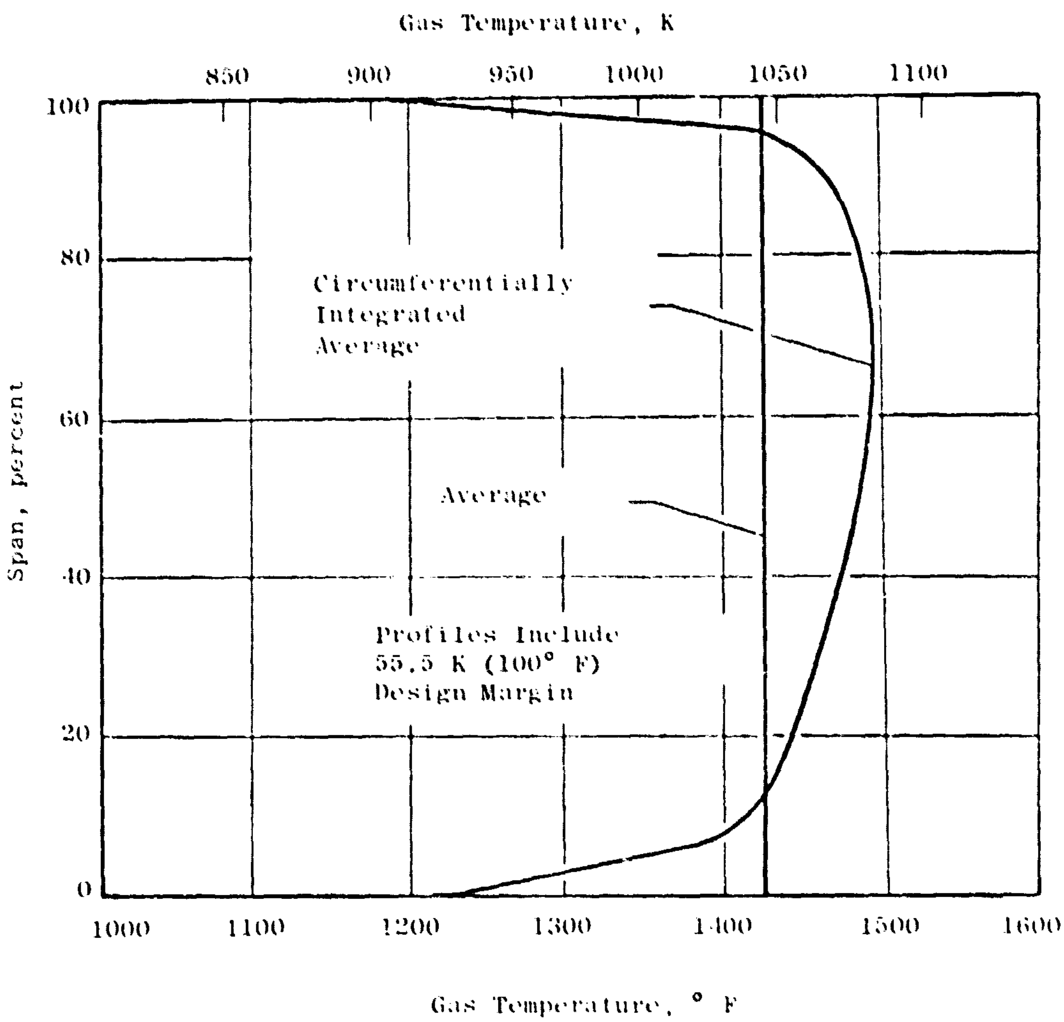


Figure 40. QCSEE Turbine Exhaust Gas Profile.

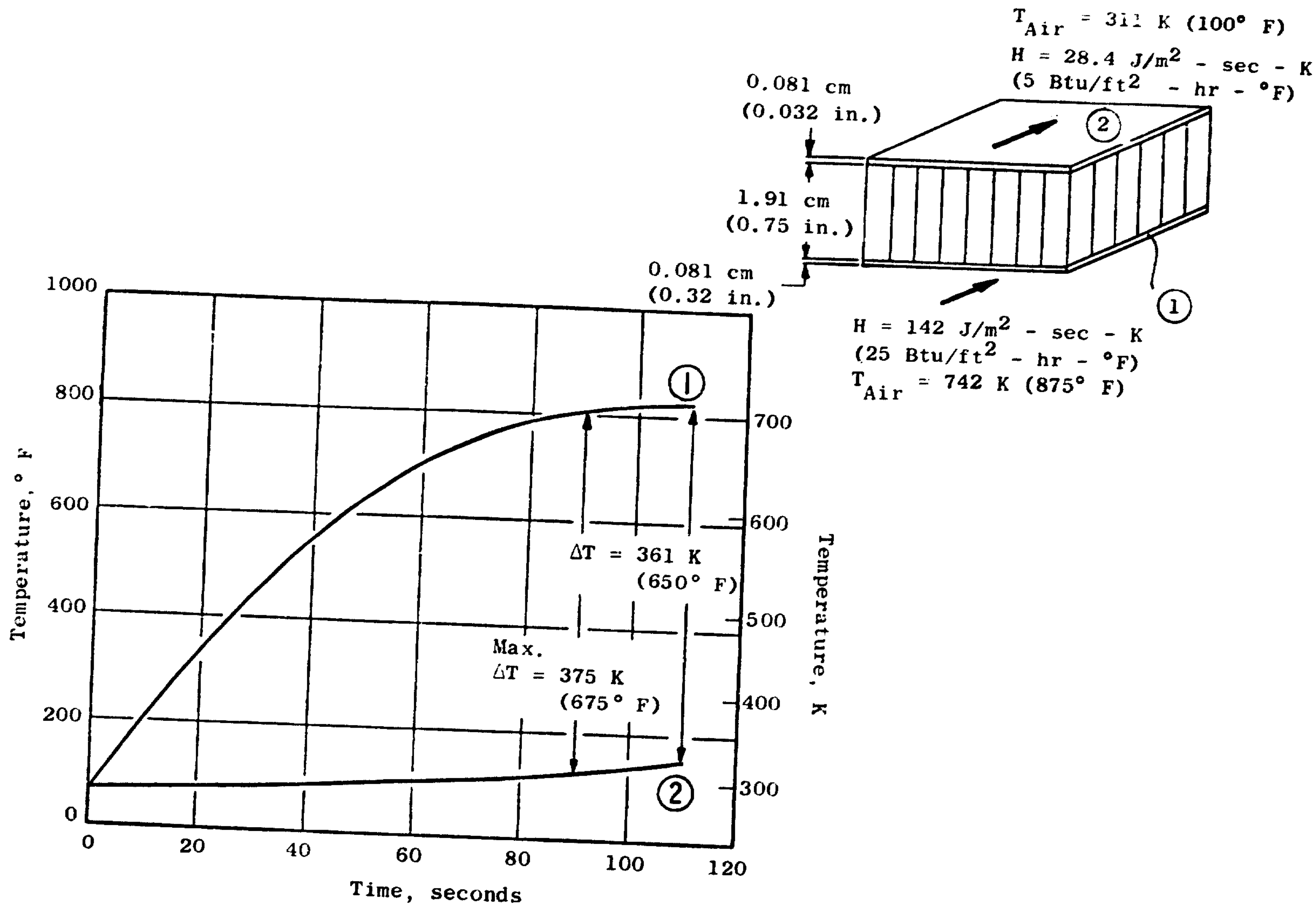
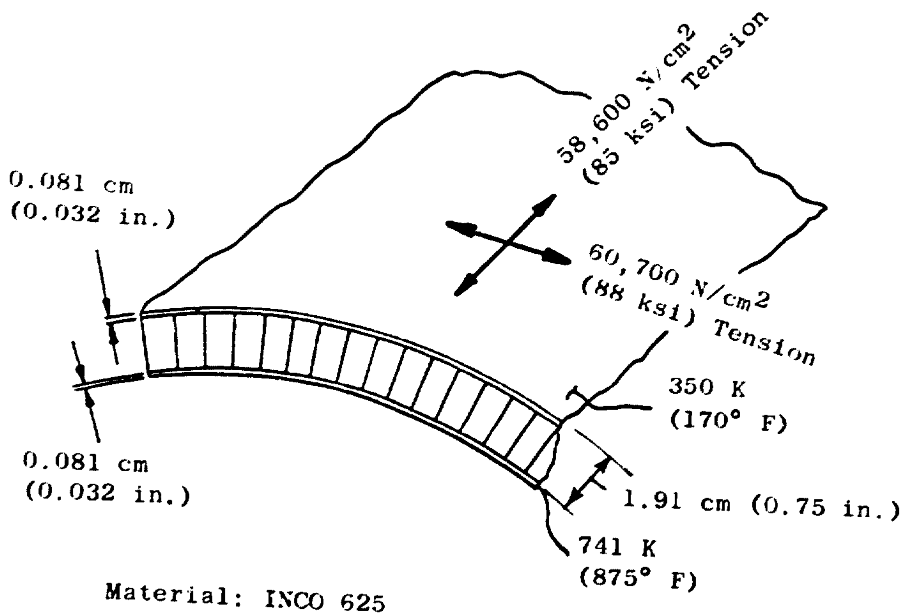
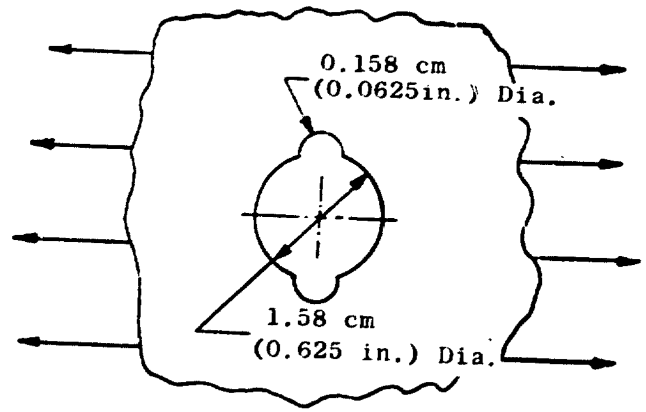


Figure 41. QCSEE Core Exhaust Nozzle Honeycomb Temperature Distribution (Material: Inco 625).





K_t = 7.25 Uniaxial Stress (Peterson)

$K_t = K_{t\ Hole} \times K_{t\ Notch}$

$K_{t\ Max.}$ = 4 Biaxial Stress

$K_{t\ Max.}$ = 9 Uniaxial Stress

Figure 42. QCSEE Core Exhaust Nozzle Stress Distribution in Brazed Acoustic Treatment.

The use of sandwich material in applications involving large temperature differences between face sheets has been a difficult problem in the past, with many failures and subsequent redesigns. The part is usually redesigned using conventional sheet metal and rib construction that is more tolerant to severe thermal cycling.

To alleviate the thermal stresses in the face sheets of the sandwich material, the unperforated face sheet was cut in both the axial and circumferential directions, as shown in Figure 43. This reduces the load-carrying capacity of the cylinder, but the sandwich material still retains effectiveness for its primary purpose of suppressing high-frequency, turbine noise. The axial and circumferential slots divide the stress field into approximately 10.2 cm^2 (4 $in.^2$) fields where shear lag in the core will reduce the thermal stress in both face sheets to acceptable levels.

Although the sandwich material is not relied upon for its structural strength and stiffness, the slots reduce the strength and stiffness of the treatment to the point that shell vibration or other strength- and durability-related problems could occur. To preclude such problems, thin-ring stiffeners (as shown in Figure 43) are attached to the inner face sheet. This type of stiffener, based on experience, does not have a thermal-stress problem.

Differential thermal expansion between the sandwich and the annular resonating-chamber assembly also must be considered during thermal cycling. The sandwich material acts as an effective insulator that shields the resonating chamber from the hot gas so that, during an engine start-up, the resonating-chamber assembly temperature lags far behind the sandwich cylinder. In fact, it was observed, during hot-gas tests on a two-dimensional stacked core treatment, that the resonators did not approach gas temperature in a time period equal to the elapsed time of 45 minutes of a typical QCSEE 402 km (250 mile) cycle mission.

The relative, radial, thermal expansion between the sandwich and the resonating chamber assembly for the outer duct is shown in Figure 44. In the room temperature or "as-built" condition, a 0.3175 cm (0.125 in.) radial gap exists. As the sandwich cylinder heats up to core gas temperature it expands radially outward, reducing the gap to zero. As the resonating chamber heats up to steady-state temperature, the radial tap again opens to 0.289 cm (0.114 in.).

A similar problem exists in the centerbody, but acts in the opposite direction. During start-up, the sandwich initially expands radially outward away from the resonating-chamber assembly. Then, as the resonating chamber heats up to its steady-state temperature, the gap closes to its original size.

The relative thermal expansion of the sandwich and the resonating-chamber assembly in the axial direction also must be considered. The sandwich is essentially fixed in the axial direction at the center of the resonating-chamber assembly and allowed to expand forward and aft into a 0.23 cm

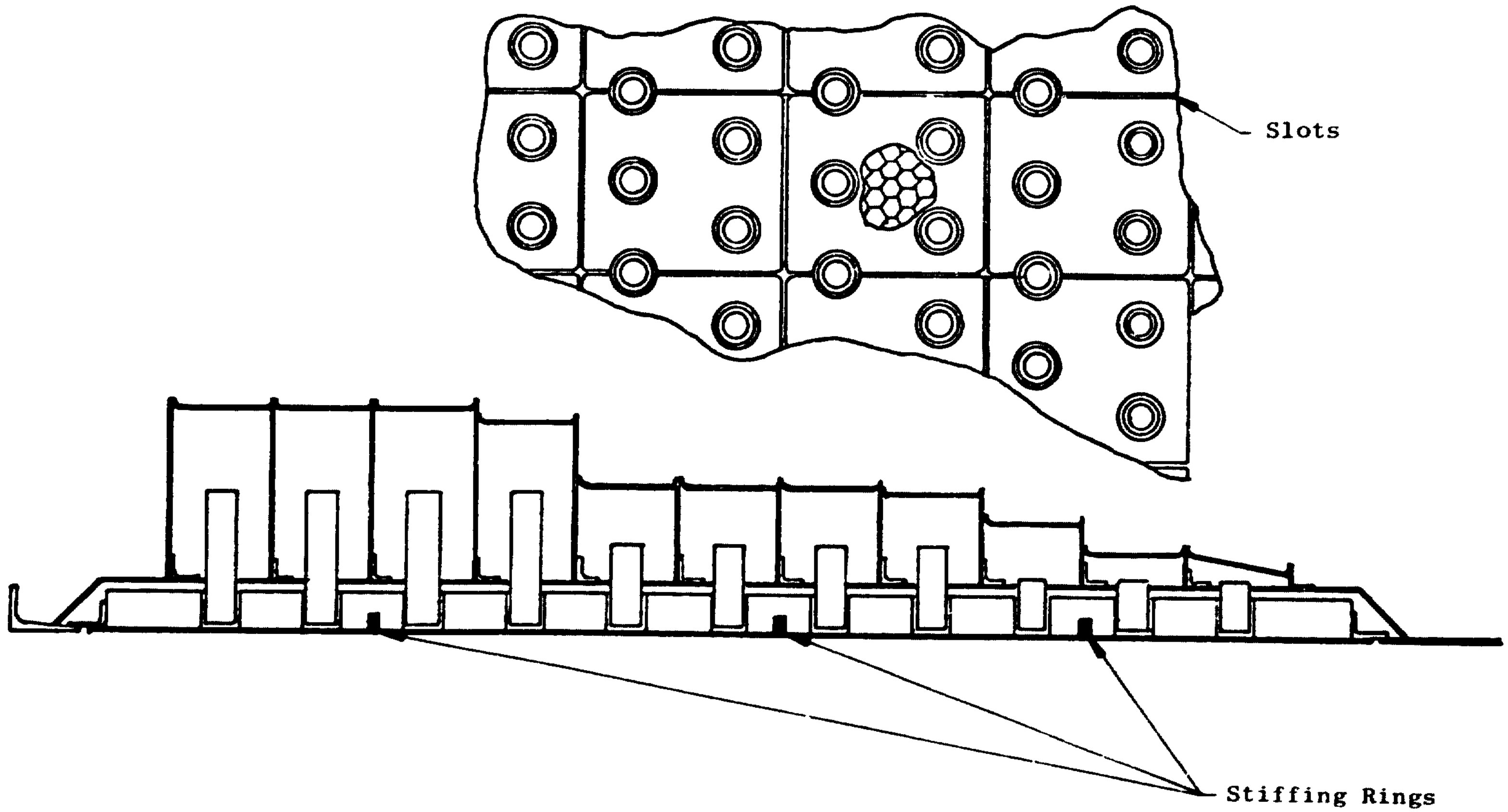


Figure 43. Outer Duct Acoustic Treatment.

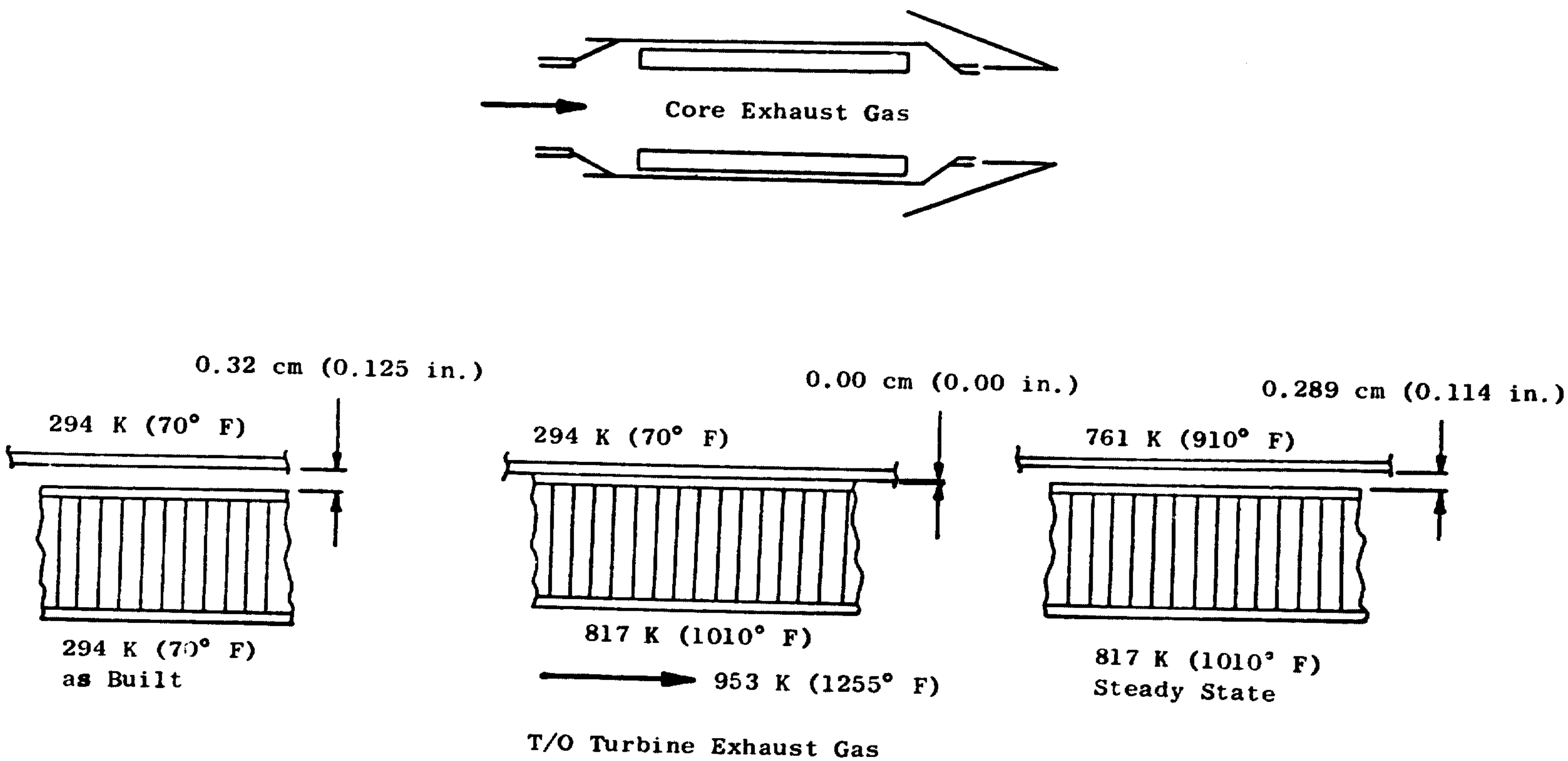


Figure 44. **QCSEE Core Exhaust Nozzle Outer Acoustic Treatment, Radial Thermal Expansion at Start-up.**

(0.090 in.) gap at each end. As the sandwich heats up to gas temperature, the gap closes and then reopens as the resonating-chamber assembly heats up to steady-state, as shown in Figure 45.

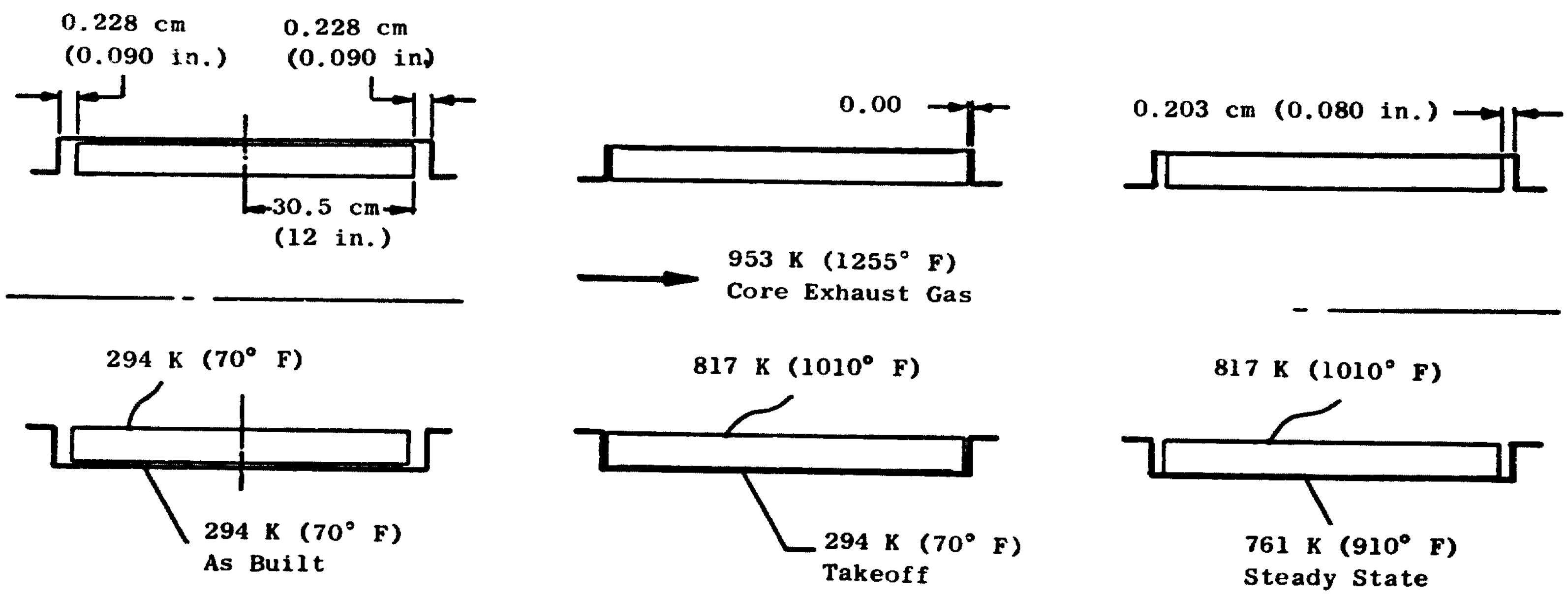


Figure 45. QCSEE Core Exhaust Nozzle Acoustic Treatment, Axial Thermal Expansion at Start-up.

SECTION VII

COMPONENT DESIGN

A. CENTERBODY

The centerbody shown in Figure 35 is treated with 61 cm (24 in.) of acoustic material designed to suppress both the high-frequency, turbine noise and the low-frequency, combustion noise. The centerbody is attached to the inner turbine frame by a 50.4 cm (19.86 in.) OD, tapered, axial flange held by fifty-five 0.79 cm (0.312 in.) bolts screwed into the self-locking nut channel on the inner turbine-frame flange. A 7.62 cm (3 in.) section of the forward flange is cut out so the centerbody can be inserted into the struts' fish-mouth seal during assembly. This design feature allows the core exhaust nozzle to be disassembled to change the acoustic treatment without removing the strut and service tubes.

The high-frequency (3150 Hz), turbine treatment is of an all-welded "stresskin" sandwich construction. The 1.9 cm (0.75 in.) thick honeycomb core is welded to an outer perforated face sheet [0.081 cm (0.032 in.) thick] and an inner face sheet [0.051 cm (0.020 in.) thick]. The perforations in the face sheet are 0.157 cm (0.062 in.) diameter with 11-12% porosity. The cell size is 0.95 cm (0.375 in.). The inner face sheet thickness, cell size, and perforation diameter were selected for acoustic considerations. The 0.05 cm (0.020 in.) thick backside face was selected to facilitate forming of the flat sandwich panels into circular cylinders.

The low-frequency, combustor, acoustic treatment consists of twelve 5.08 cm (2 in.) wide resonating chambers. The four forward chembers were sized to suppress the 315 Hz noise; the center, 500 Hz, and the four aft chambers were designed to suppress 400 Hz noise. Communication with the resonating chambers through the sandwich cylinder is by 593 tubes, 1.58 cm (0.625 in.) in diameter, providing a porosity of 10% of the surface area. The tubes are welded to the shell of the resonating chamber. They project a specified distance into the resonating chamber and are 0.076 to 0.177 cm (0.03 to 0.07 in.) below the gas-side flow surface of the sandwich. The tube access holes in the sandwich cylinder are oversized to permit free, axial, thermal expansion of the sandwich cylinder relative to the resonating-chamber assembly. The length of the tube and the depth or volume of the resonating chamber were designed to suppress a specific frequency band.

The outer shell of the resonating-chamber assembly is the structural or load-carrying member of the centerbody. It supports the sandwich cylinder by a retaining ring at each end, but has an expansion gap to permit the sandwich cylinder to freely expand axially during thermal cycling.

The centerbody plug is bolted to the aft flange of the centerbody so that the acoustically treated centerbody can be easily replaced. A 12.5 cm (5 in.) diameter hole in the aft end of the plug allows the piston balance air from the sump to be discharged at a low back pressure.

A hard-wall centerbody, that is interchangeable with the acoustically treated centerbody, also was designed. Both the forward and aft flanges are identical to the acoustically treated centerbody. The shell is 0.152 cm (0.060 in.) thick with four stiffening rings welded to the inner surface.

B. OUTER DUCT

The outer duct shown in Figure 35 also is designed to suppress high-frequency, turbine and low-frequency, combustor noise (as previously described for the centerbody). The outer duct is attached to the outer turbine-frame flange by seventy-eight 0.635 cm (0.25 in.) bolts. The front flange has a 7.92 cm (3.12 in.) gap at the bottom centerline to clear the strut during assembly and permit changing the acoustic treatment, as in the centerbody design.

The high-frequency acoustic treatment uses the same sandwich treatment as described for the centerbody. The low-frequency treatment is also similar to the centerbody; but, because of the limited envelope at the aft section, the resonating-chamber depth could not be designed for 400 Hz but is effective in the 630 to 1600 Hz range. The porosity of the outer duct is 7% with a total of 635 tubes.

Space limitation also required local cutouts in the resonating-chamber assembly for two fan cowl hinges. The outer duct must be lowered to clear the hinges before it can be assembled to the turbine-frame flange. An axial slot that would allow the outer duct to be pulled directly aft would have required the elimination of an excessive amount of acoustic treatment. An axial slot at the bottom centerline also was required for the clearance of the oil seal drain line.

C. OUTER NOZZLE

The aft outer cone and the outer nozzle cowl form the inner boundary of the fan exhaust nozzle, and the exit boundary of the core nozzle, as shown in Figure 46. The aft outer cone has an angle of 0.218 radians (12°30'). The outer nozzle cowl is also a cone with 0.2 radians (11°30') angle. The outer duct, cone, and cowl are bolted together so that similar parts are interchangeable, and the proper length cowl can be selected for the OTW and UTW engines or for tests requiring other core nozzle areas (Figure 46).

The outer aft cone has a 0.635 cm (0.25 in.) thick by 4.83 cm (1.9 in.) wide ring at the forward end. The ring is used for stiffening the forward end of the cone and as a wear ring for the sliding interface fit between the core exhaust nozzle and the fan cowl. The sliding interface is required to accommodate the axial, thermal expansion of the core exhaust nozzle during high temperature operation. The riveted boss on the core cowl is the termination of the seal drain line. The oil leakage is dumped overboard.

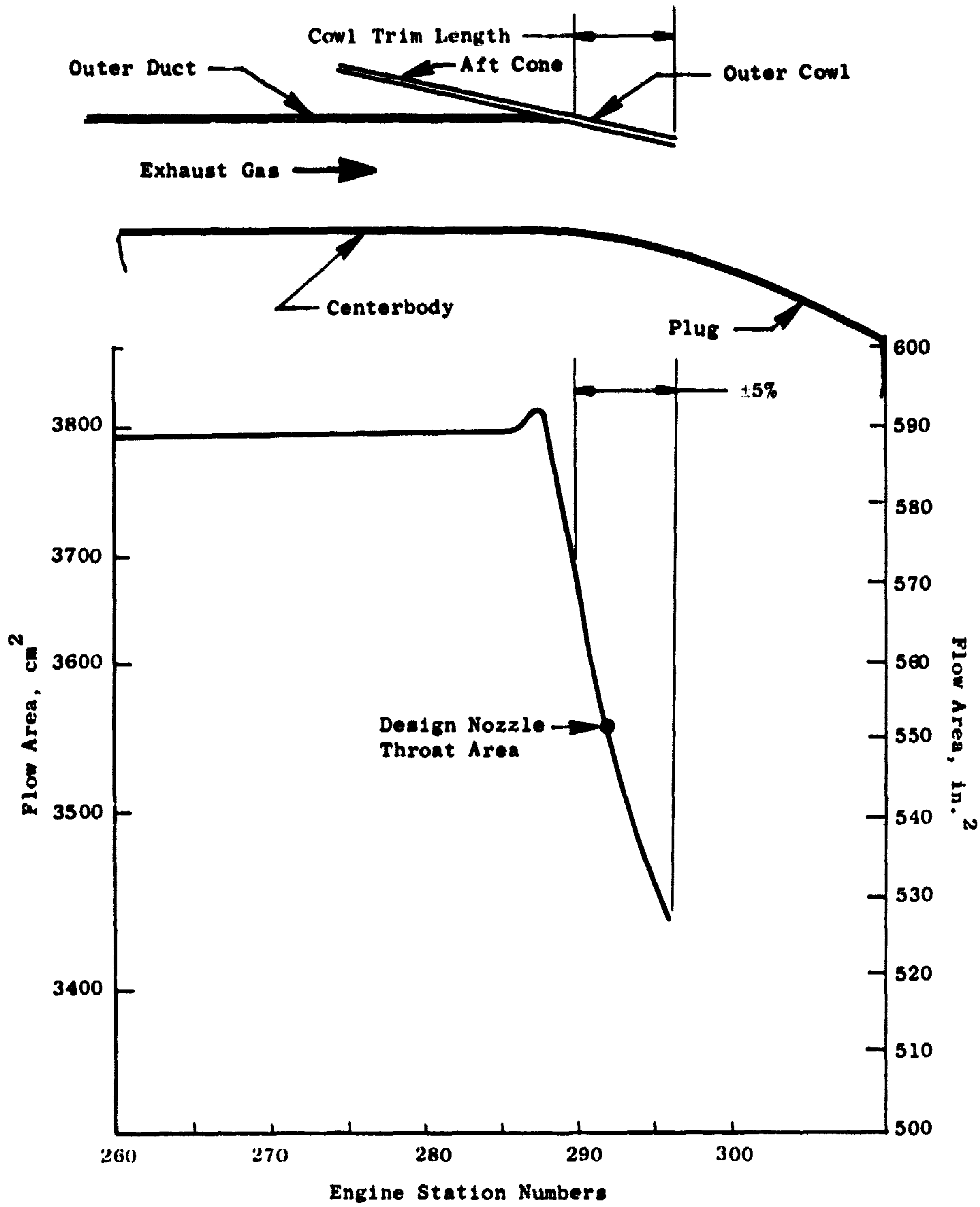


Figure 46. UTW Core Exhaust Nozzle Area Trim.

During UTW engine operation, the pressure differential across the outer cone is essentially zero, with near ambient pressure on both surfaces. It has been estimated during OTW operation that approximately 1.31 N/cm^2 (1.9 psi) pressure differential can exist across the cone. The calculated critical elastic-buckling pressure across the cone was 3.1 N/cm^2 (4.5 psi). The resulting safety factor is 2.4.

During engine start-up, the outer duct heats up and expands radially outward. The outer cone and cowl, however, remain essentially at ambient temperature because the fan stream temperature is only 330° K (135° F). To accommodate the differential expansion, the outer duct is bolted to the outer cone and cowl through a 0.08 cm (0.032 in.) thick sheet metal expansion cone, as shown in Figure 47. The stress in the expansion cone for a given temperature differential is a function of its thickness, length, and slope. The thermal stress in the expansion ring is above the 28,200 N/cm^2 (41,000 psi), 0.2% yield strength of Inconel 625; however, based on low cycle fatigue analysis, the joint is capable of 6,500 cycles with a stress concentration factor of 2.5.

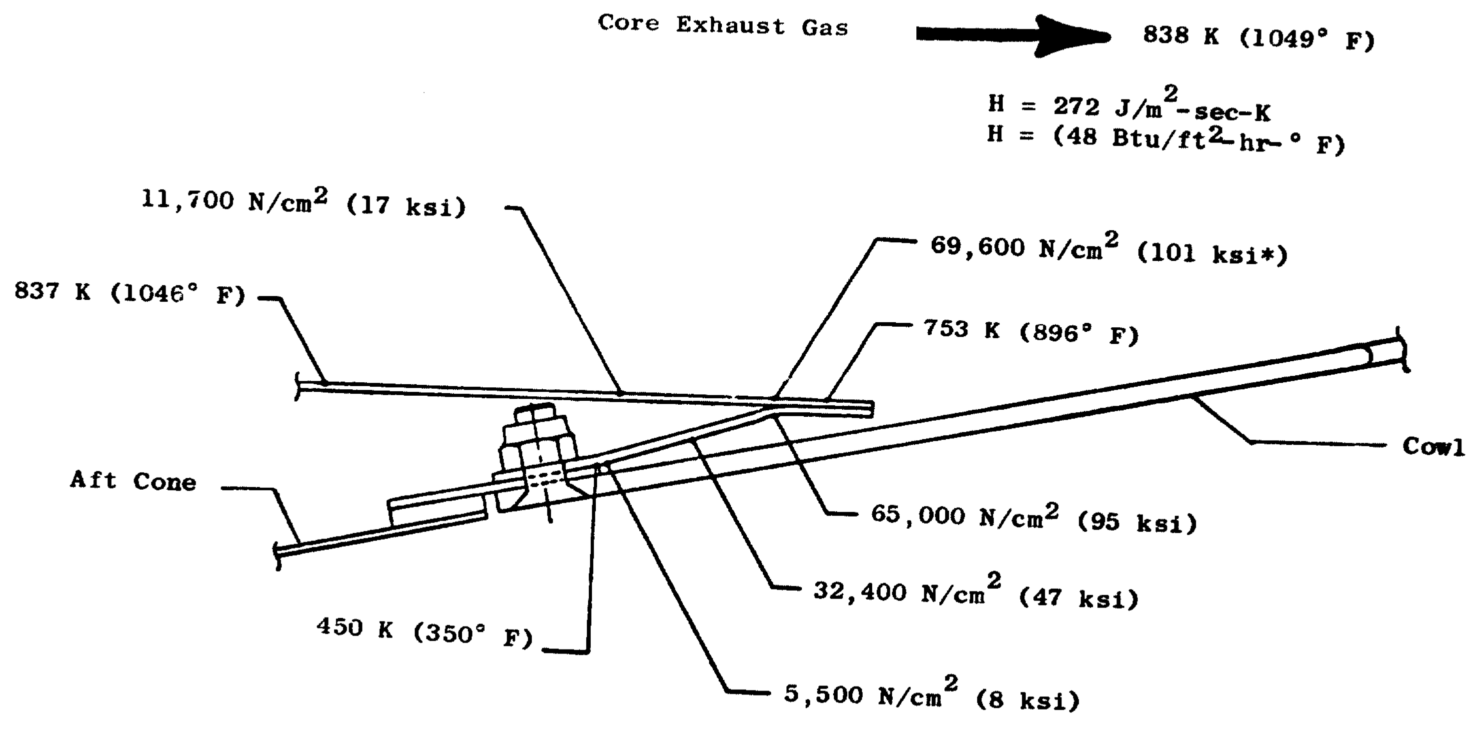
D. STRUT

The radial service-line strut located at the bottom centerline of the core exhaust nozzle provides an aerodynamic fairing over the oil-in, oil drain, seal drain, and piston balance air liners that, in the experimental engine, are routed through the core nozzle to the sump. The strut is aerodynamically shaped, with a chord-to-width ratio of four, to minimize pressure loss due to local flow blockage. The strut width was designed to permit the tubes to be inserted through the strut at assembly.

Disassembly of the strut and service lines is not required to interchange the acoustic and hard-wall treatments in the core exhaust nozzle. The strut assembly has a fish-mouth seal that engages the cutout in the centerbody, The strut is bolted to the outer turbine-frame flange and along the edge of the cutout in the outer duct. A slip joint between the strut and the centerbody can accommodate the radial, differential, thermal expansion between the strut and the inner and outer acoustic treatment. A two-piece, airseal plate is bolted at each end of the strut to minimize air leakage through the strut.

E. SERVICE TUBES

In the experimental engine, the service tubes are routed through the strut to the turbine sump. The following maximum unsupported length for the tubing is based on the graphical solutions given in Tubing Fatigue Analysis Method, General Electric Report TM 70-316, for a maximum engine speed of 15,192 rpm or 253 Hz.



* 0.2% Y.S. at 756 K (900° F) = 28,270 N/cm² (41 ksi), -3 σ

LCF Life at 8110 K (1000° F) = 6500 Cycles, -3 σ

$K_t = 2.5$

Figure 47. QCSEE Core Exhaust Nozzle Thermal Stress at Start-up.

Description	Size, cm (in.)	Maximum Unsupported Length, cm (in.)
Oil in	1.27 (0.51) OD × 0.089 (0.035) wall	37.4 (14.7)
Scavenge	1.9 (0.75) OD × 0.089 (0.035) wall	41.3 (16.28)
Shop air	1.9 (0.75) OD × 0.089 (0.035) wall	46.4 (18.25)
Oil drain	0.63 (0.250) OD × 0.089 (0.035) wall	25.4 (10.0)

SECTION VIII

INSTRUMENTATION

Instrumentation of the cone exhaust nozzle is limited to performance testing with the hard-wall centerbody and outer duct and is not provided for in the acoustic tests. Eight rake pads and four static taps are provided for performance measurements at engine Station 262.0. The types of instrumentation and their locations are as follows:

Description	Sensor	Angular Locations AFT Looking Forward, Radians (degrees)
Rake	PT	0.27 (15.5)
Static tap (outer wall)	PS	0.41 (23.5)
Static tap (inner wall)	PS	0.27 (15.5)
Rake	TT	1.16 (67)
Rake	PT	2.06 (118.4)
Rake	TT	2.51 (144.0)
Rake	PT	3.86 (221.2)
Rake	TT	4.31 (247.0)
Static tap (outer wall)	PS	4.46 (256.0)
Static tap (inner wall)	PS	4.31 (247.0)
Rake	PT	5.21 (298.4)
Rake	TT	5.65 (324.0)

SECTION IX

ASSEMBLY PROCEDURE

The core exhaust nozzle was designed for maximum interchangeability between the acoustic treatment and the hard-wall assemblies for both the UTW and OTW engines. The centerbody and the outer duct have a cutout in the forward flange to fit around the strut, so that the service tubes and strut do not have to be disassembled to change acoustic treatment.

The core exhaust nozzle is assembled as follows:

1. Insert service tubes in the strut assembly.

2. Make all sump connections.

3. Bolt the strut assembly with tubes to the outer turbine-frame flange.

4. Slide the centerbody forward to engage the fish-mouth seal on the strut, and bolt the forward flange to the inner turbine-frame flange.

5. Bolt the plug to the aft centerbody flange.

6. Slide the outer duct over the centerbody to clear the fan cowl hinges.

7. Bolt the outer duct to the outer turbine-frame flange and the strut assembly.

8. Slide the outer cone over the expansion flange of the outer duct.

9. Slide the aft cowl over the outer duct and bolt the outer duct, aft cone, and cowl together.

10. Insert the seal drain extension tube in the outer cone drain boss and make the tube connection at the strut.

SECTION X

NONFLIGHT-WEIGHT NOZZLE WEIGHT SUMMARY

The calculated weight breakdown of the nonflight, core exhaust nozzle is as follows:

	Hard Wall, kg	Hard Wall, lb	Acoustic Treated, kg	Acoustic Treated, lb
Centerbody	18.9	41.8	60.6	133.7
Plug	7.4	16.3	7.4	16.3
Outer duct	33.3	73.5	105.0	232.1
Outer aft cone	11.5	25.3	11.5	25.3
Outer cowl	14.9	32.8	14.9	32.8
Strut	1.7	3.8	1.7	3.8
Service tubes	1.4	3.0	1.4	3.0
Bolts, nuts, etc.	1.8	4.0	1.8	4.0
TOTAL	90.9	200.5	204.3	451.0

SECTION XI

FLIGHT-WEIGHT NOZZLE

A preliminary layout of a flight-type, nonacoustic core exhaust nozzle, based on the flowpath shown in GE drawing 4013205-036, is shown in Figure 48. The core nozzle is designed for aircraft using a 914 m (3,000 ft) runway, which does not require an acoustically treated nozzle to meet the noise requirements of the QCSEE program. The estimated weight of a flight-type UTW core exhaust nozzle is as follows:

QCSEE FLIGHT CORE EXHAUST NOZZLE

Weight Summary, kg (lb)

Centerbody	20.4	(44.9)
Outer nozzle	40.0	(97.1)
TOTAL	64.4	(142.0)

FOLDOUT FRAME

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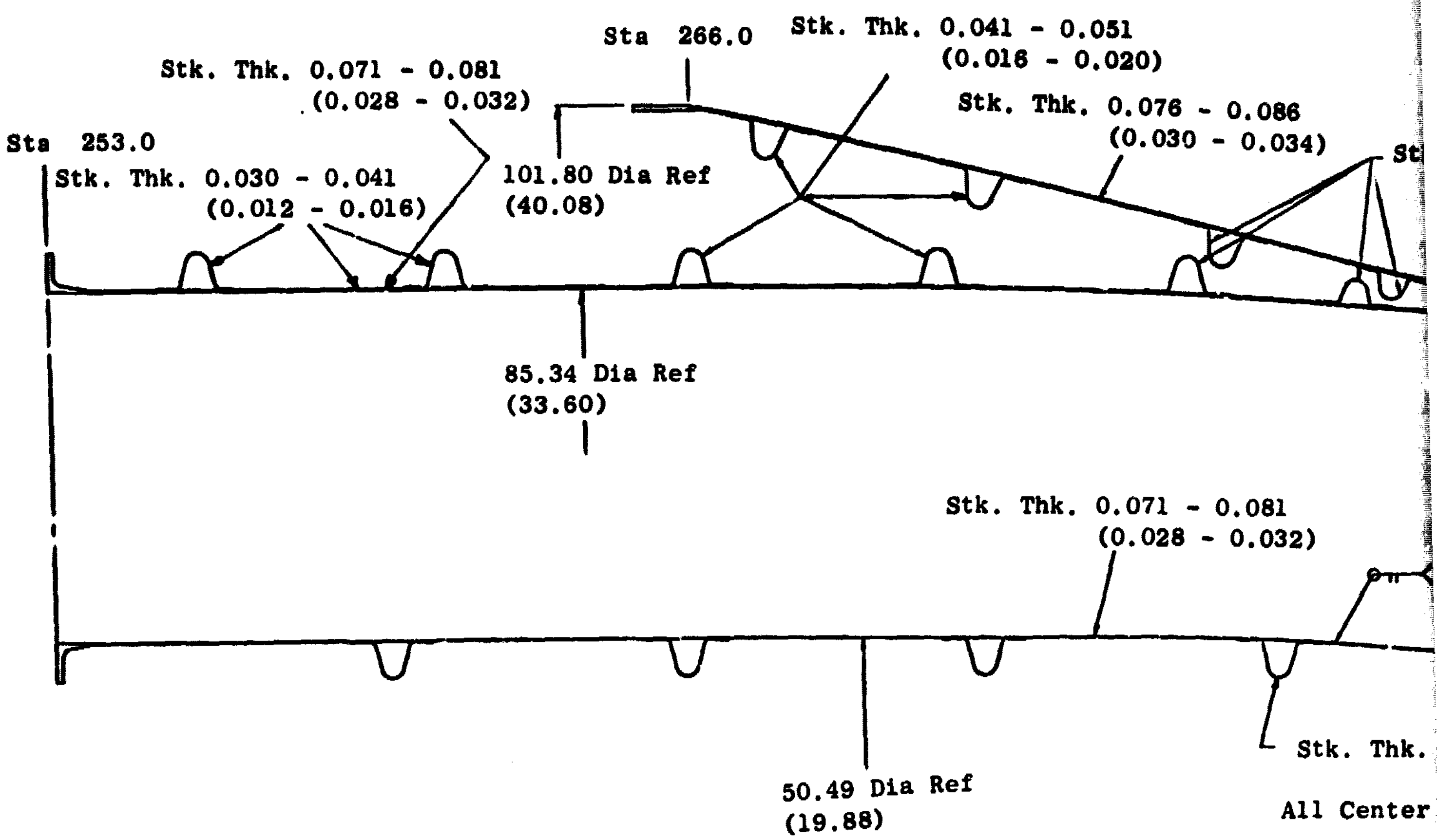

Figure 48. Preliminary of a Flight-Type

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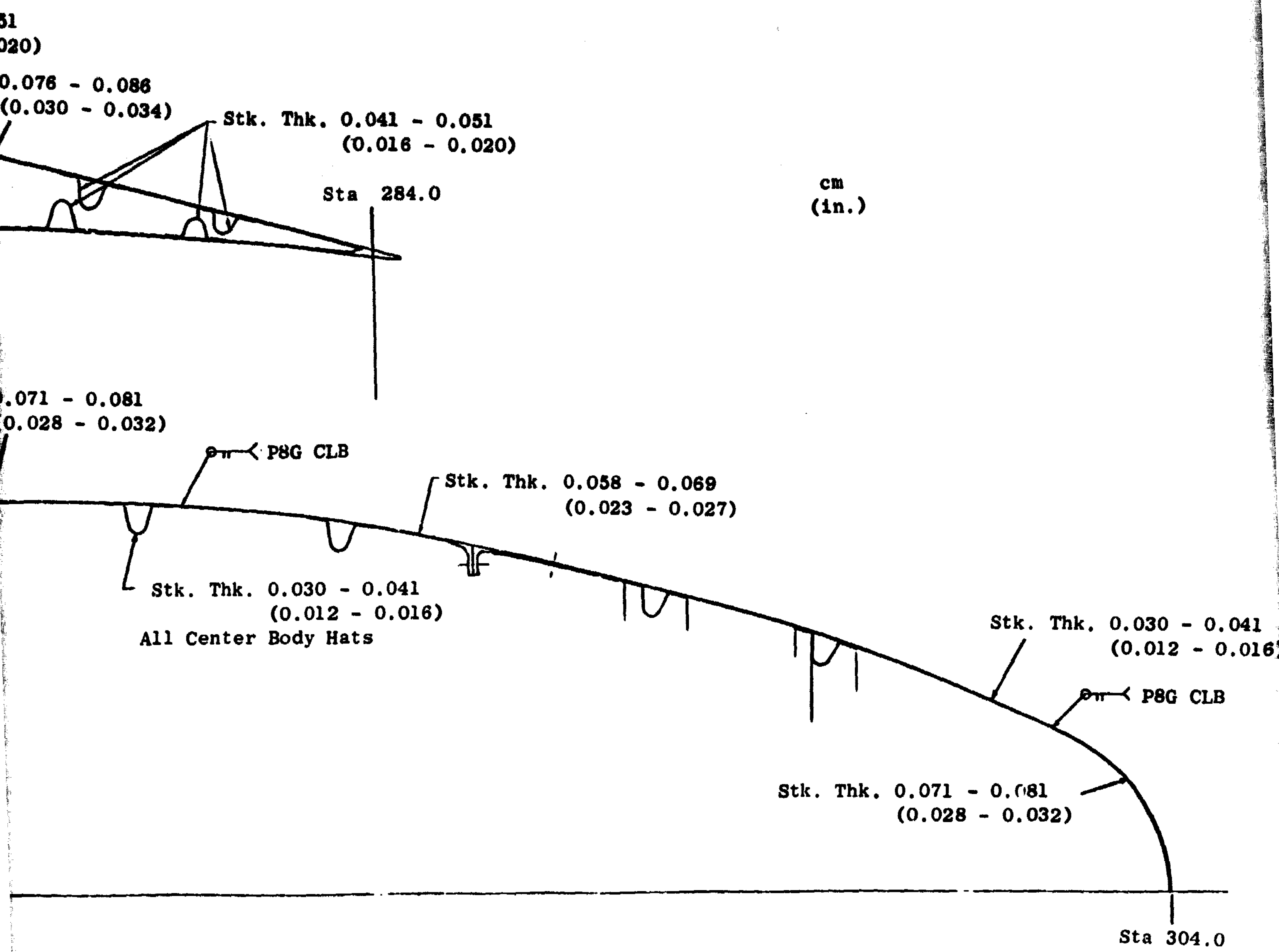
FOLDOUT FRAME 2



ary of a Flight-Type (Non-Acoustic) Core Exhaust Nozzle.

SECTION XII

MANUFACTURING

The QCSEE Core Exhaust Nozzle was fabricated at the General Electric Edwards Flight Test Center in Mojave, California. The fabrication was started in July, 1975 and completed on February 1, 1976.

The various stages in fabricating the core exhaust nozzle are shown in the following paragraphs. Figure 49 shows the acoustically treated centerbody after the 593 holes were drilled through the sandwich cylinder. The welding of the center row of tubes in the centerbody is shown in Figure 50. The assembled acoustic centerbody with the plug and strut are shown in Figure 51. The hard-wall centerbody is shown in Figure 52.

The acoustically treated outer duct, during the later stages of fabrication, is shown in Figure 53. The welding of the cover pad over the local cutout in the acoustic treatment to provide clearance for the fan cowl hinge is shown in Figure 54.

The assembled core exhaust nozzle with the acoustic-treated outer duct and centerbody is shown in Figure 55. The hard-wall assembly is shown in Figure 56.

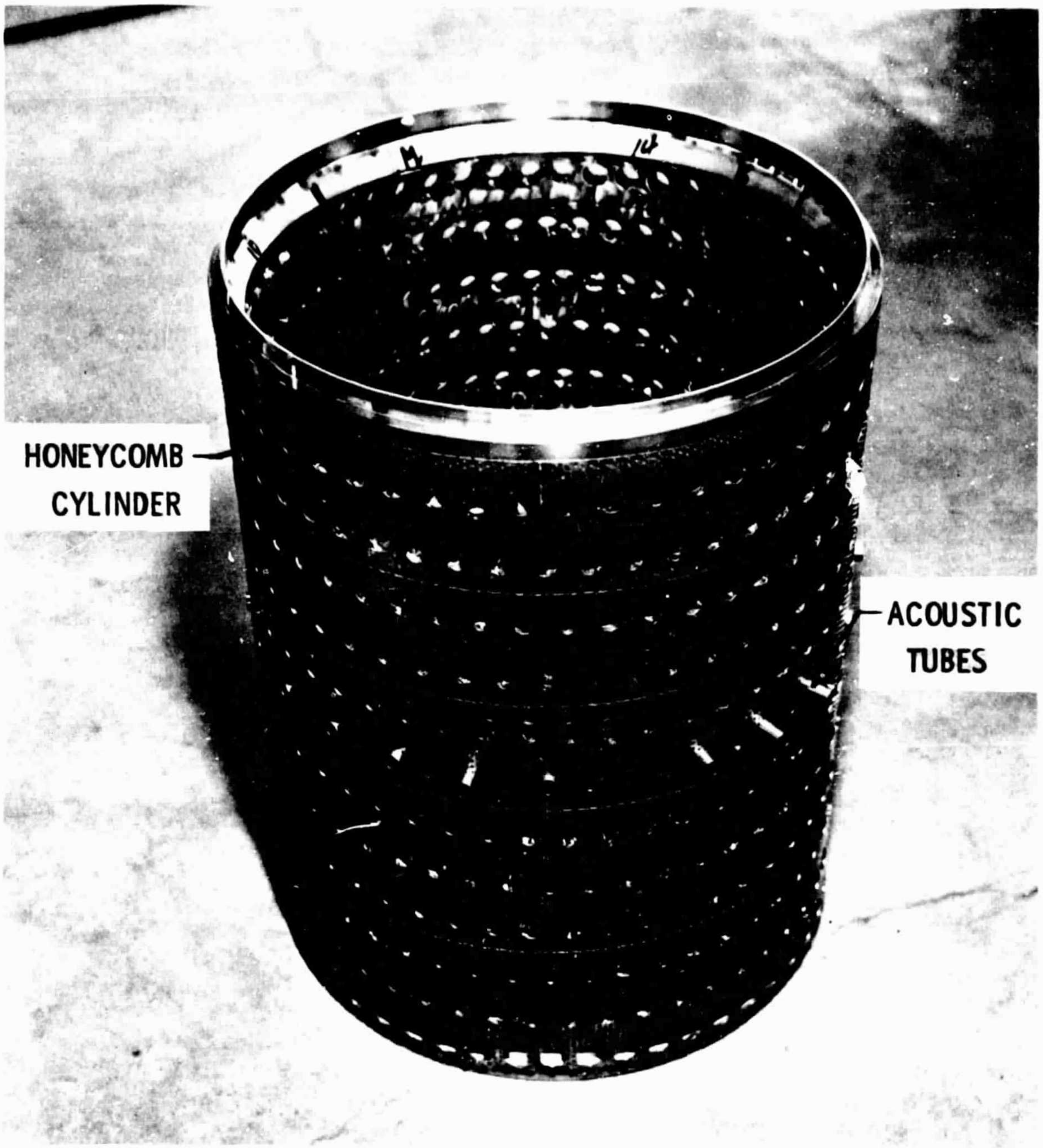


Figure 49. Acoustic Centerbody Treatment for the QCSEE Core Exhaust Nozzle Before Assembly of the Resonator Chambers.

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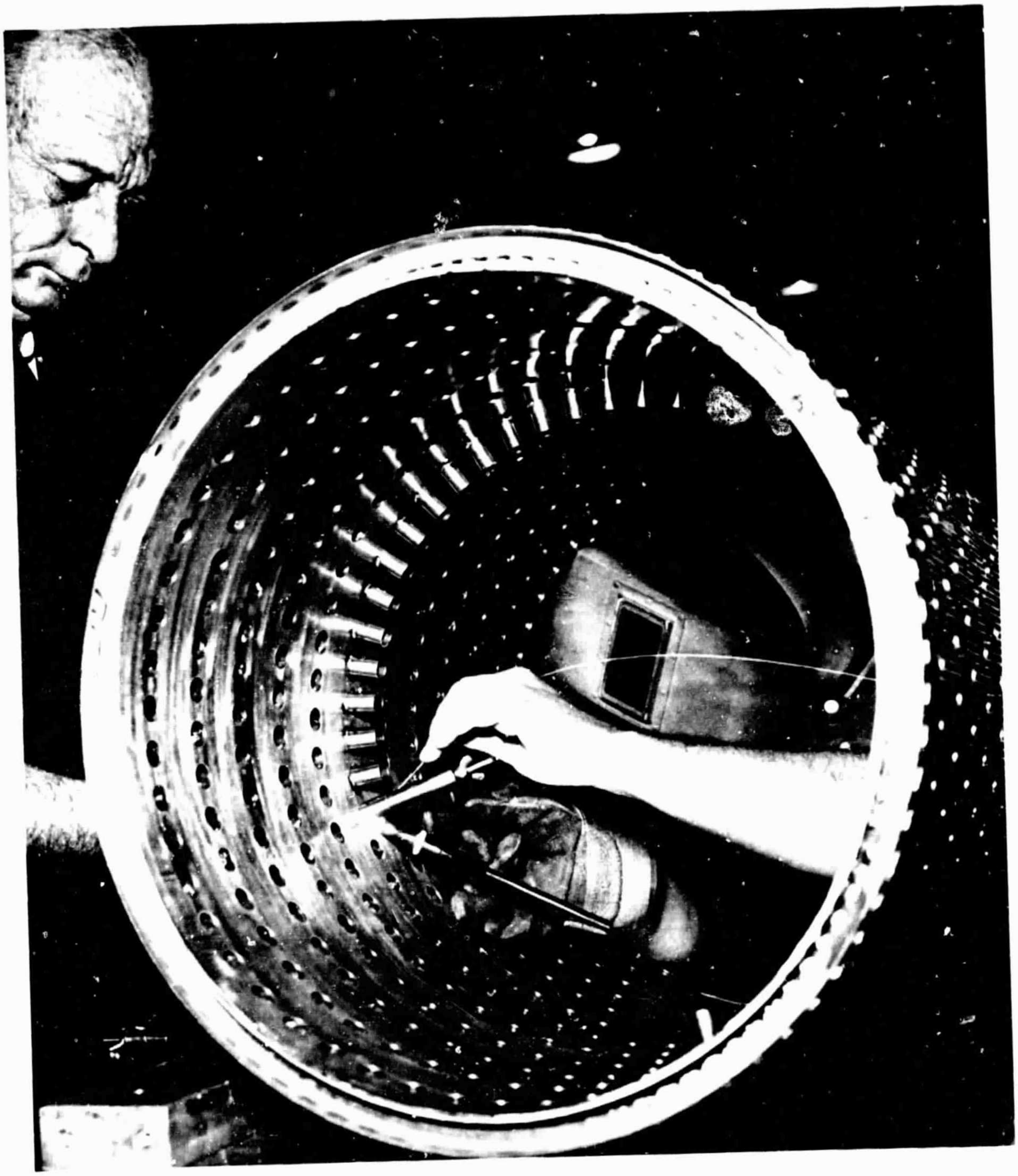

Figure 50. Welding Acoustic Tubes into the Centerbody, QCSEE Core Exhaust Nozzle.

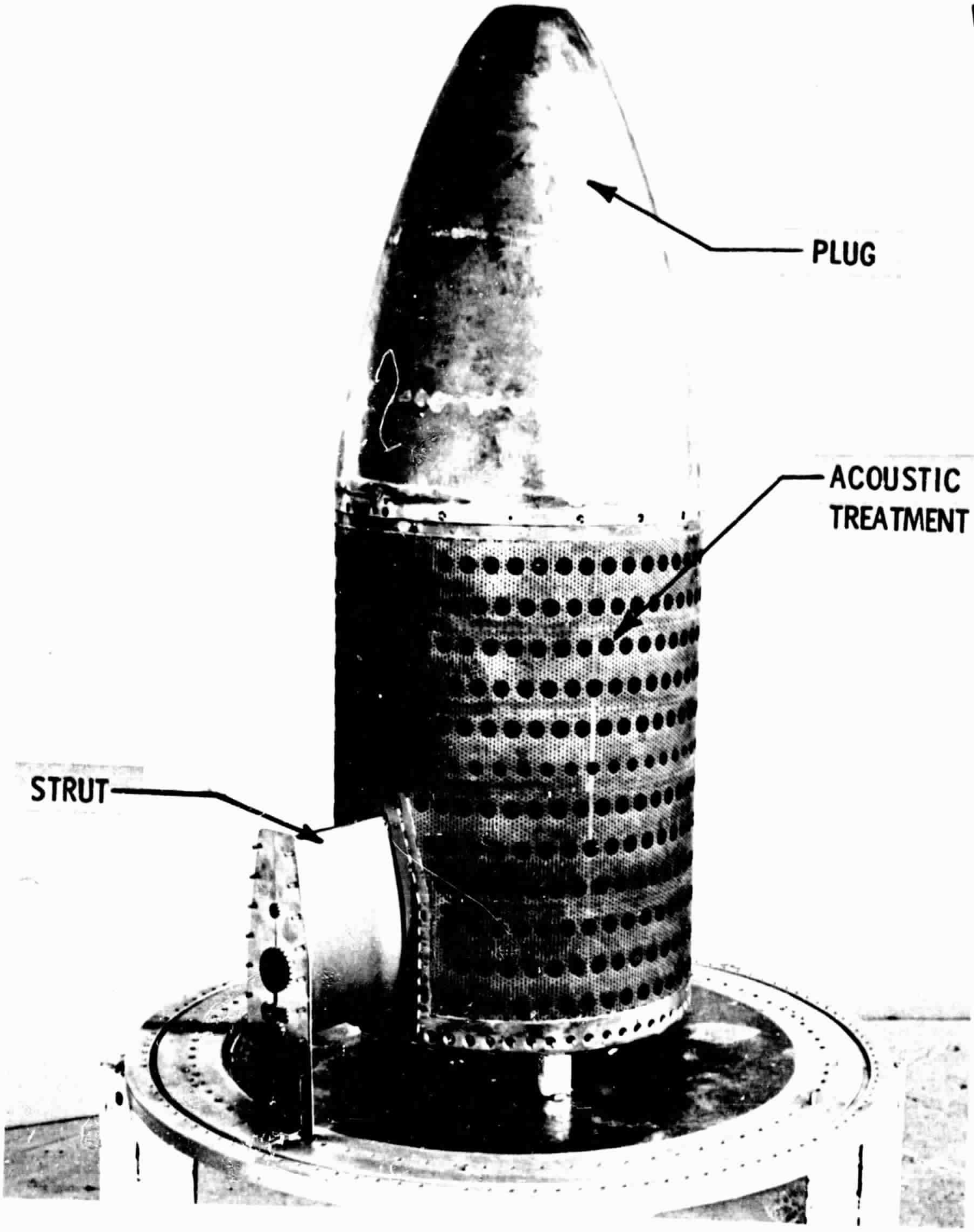

Figure 51. QCSEE Acoustic Treated Centerbody.

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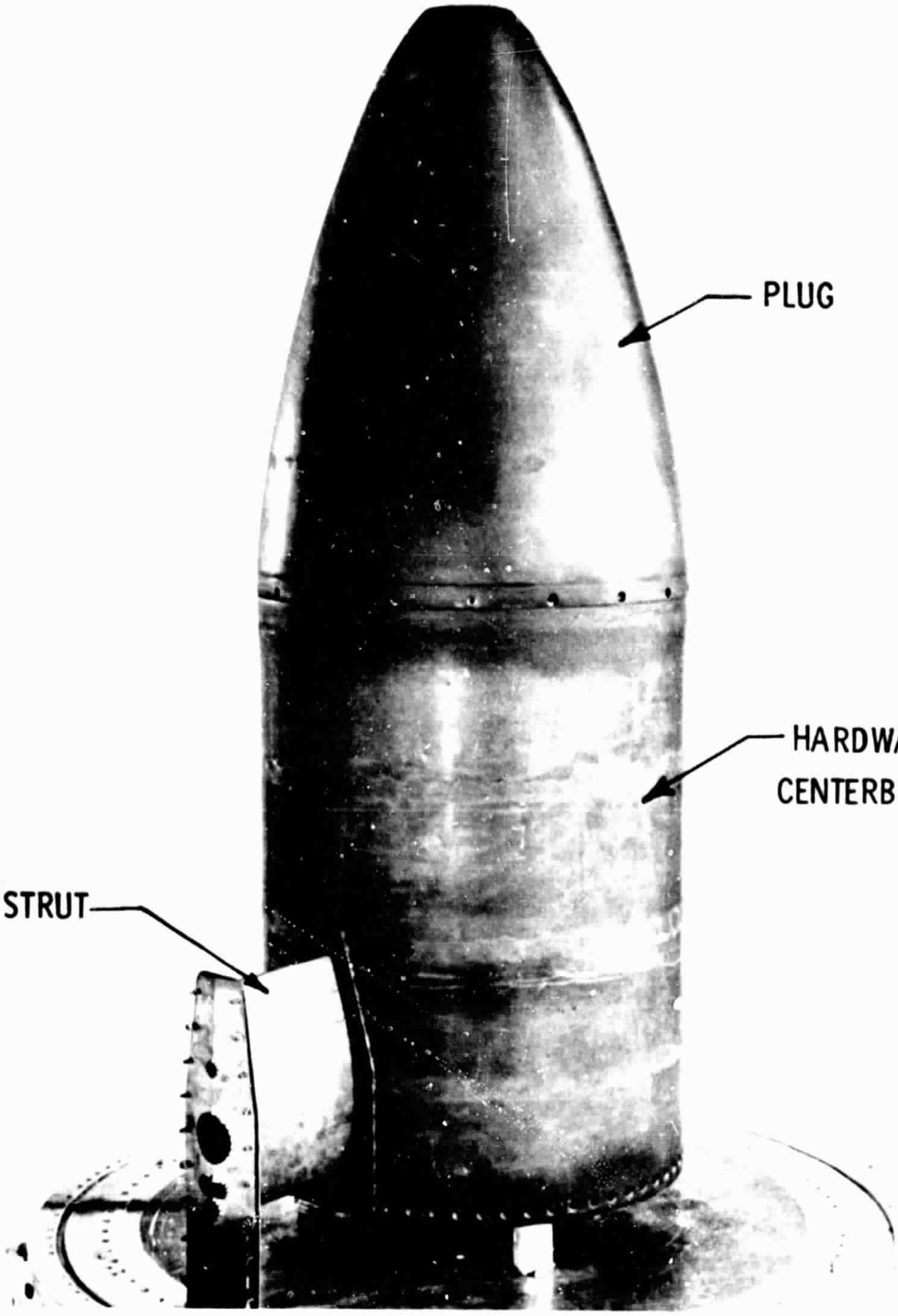

Figure 52. QCSEE Hard Wall Centerbody.

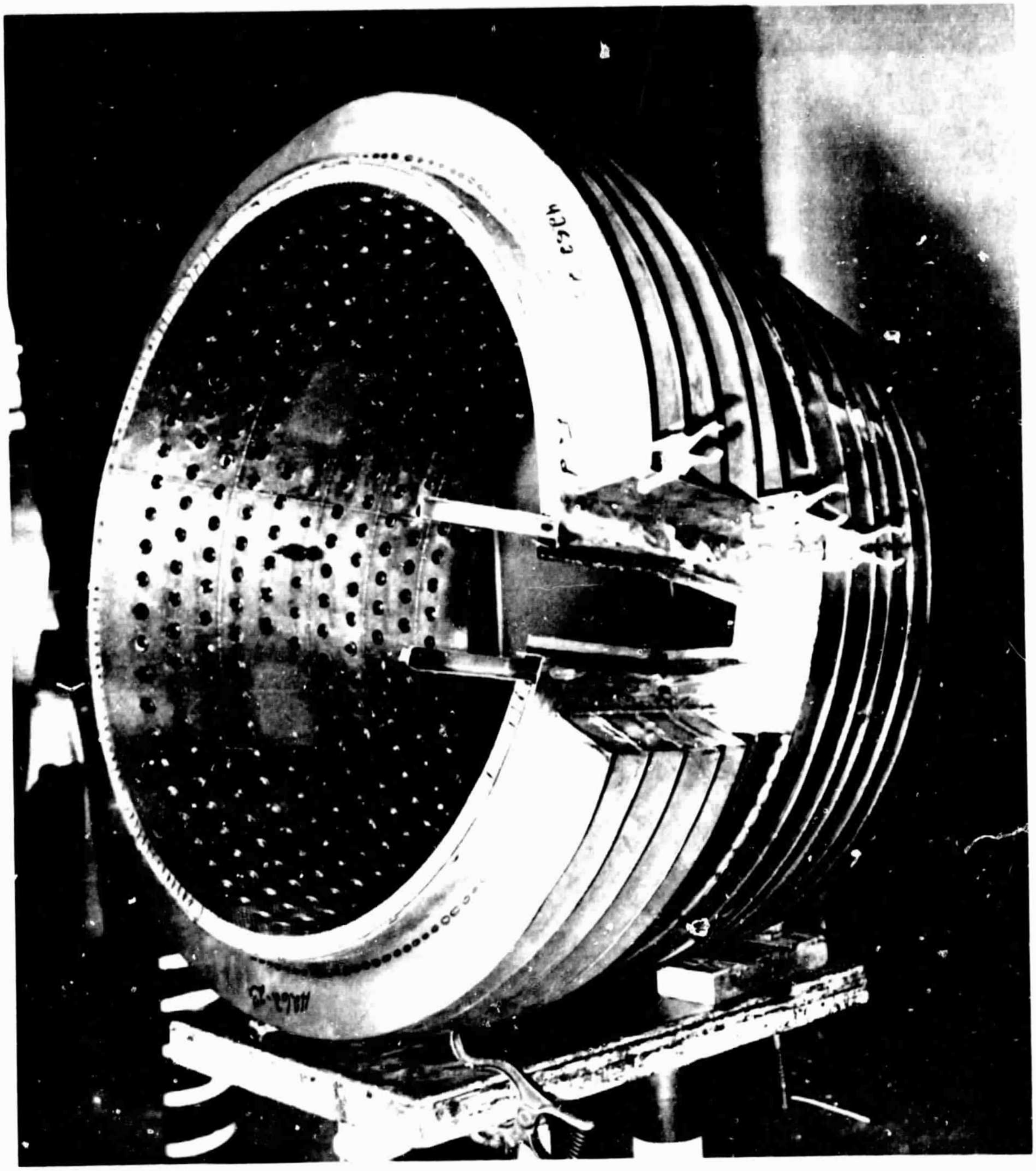

Figure 53. Fabrication of Acoustic Outer Duct, QCSEE.

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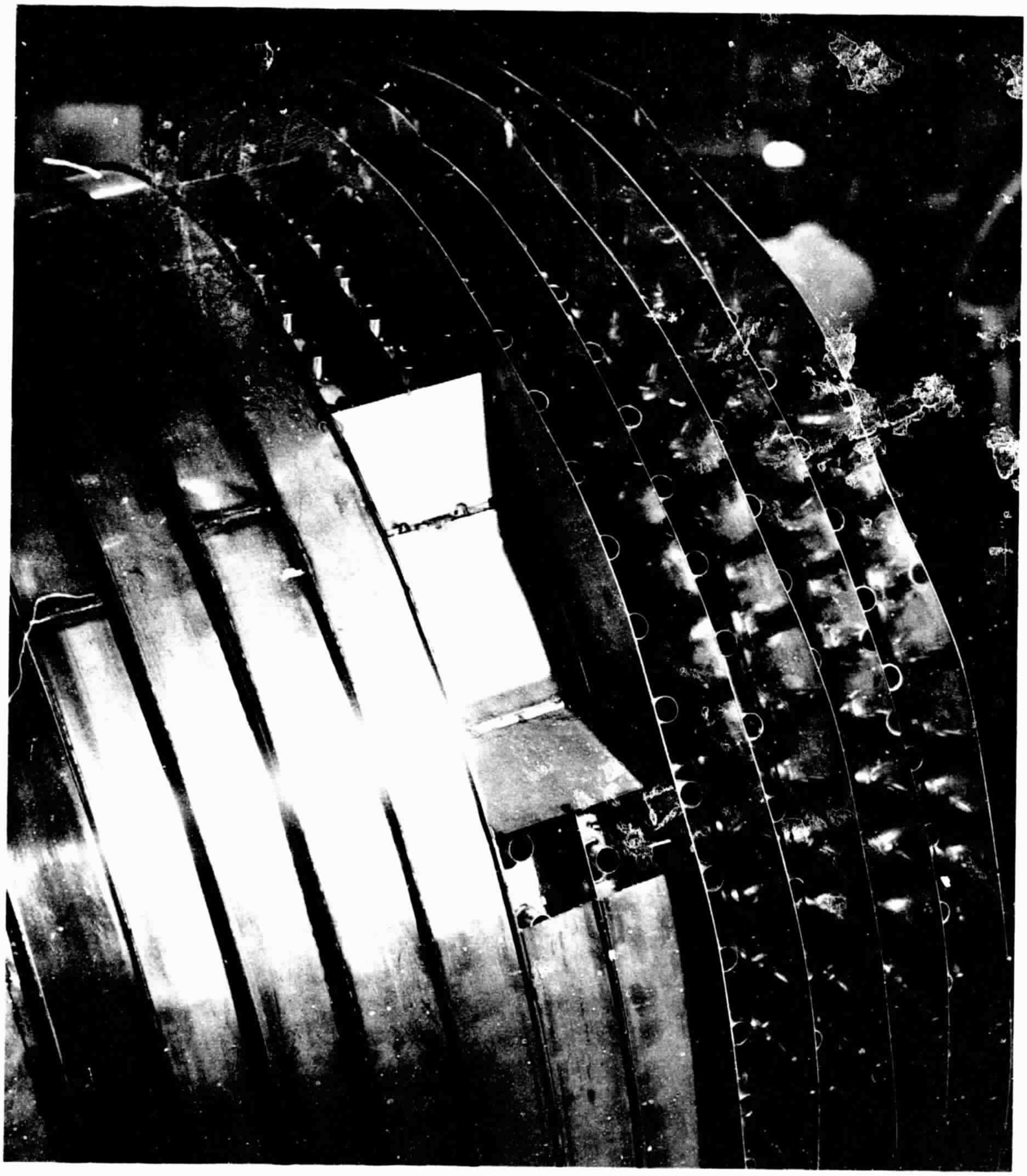

Figure 54. Assembling Acoustic Outer Duct Showing Local Cut-out Area for Cowl Hinges, QCSEE.

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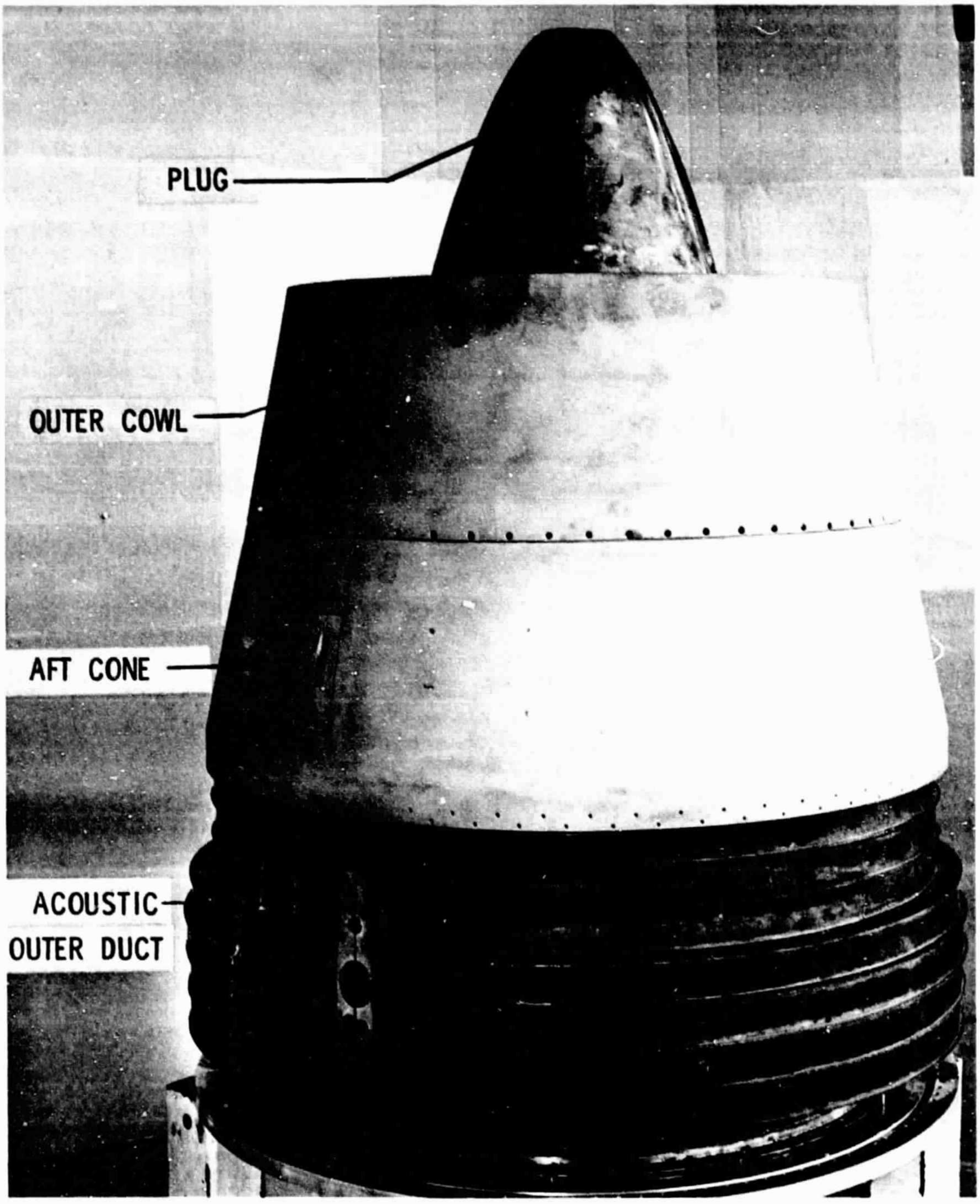

Figure 55. QCSEE Acoustic Core Exhaust Nozzle.

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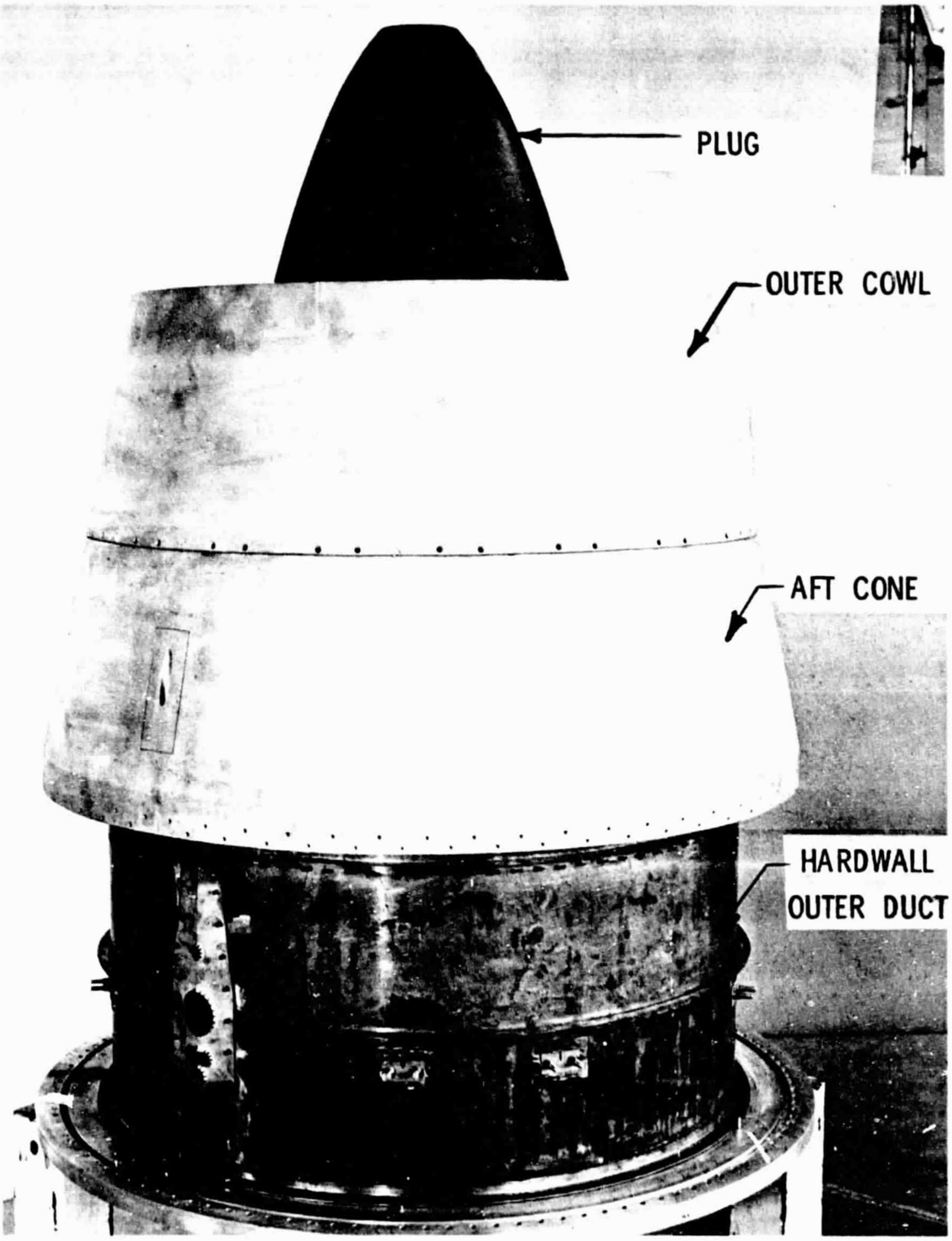

Figure 56. QCSEE Core Exhaust Nozzle.

APPENDIX I

UTW BOILER PLATE NACELLE DRAWING LIST

56J119602	UTW Boiler Plate Nacelle Installation
56J119603	Fan Cowl Assembly
56J119605	Pylon Assembly
56J119606	Inlet Assembly
56E119608	Rings - Spec Control, Fan Cowl
56E119609	Retainer - Spec Control, Fan Cowl
56J119610	Door Assembly - Core Cowl
56J119611	Skins - Spec Control, Core Cowl and Apron
56J119612	Skins - Flat Pattern, Core Cowl
56J119613	Rings - Core Cowl
56B119614	Ring - Closure, Sta. 202.25, Core Cowl
56B119615	Apron - Core Cowl
56B119616	Ring - Aft, Sta. 274.00, Core Cowl
56J119617	Keel-Bottom, ℄ , Core Cowl
56J119618	Hinges - Core Cowl
56J119620	Acoustic Panels - Core Cowl
56E119621	Rings - Fan Cowl
56E119622	Rings - Fan Cowl
56J119623	Skins - Spec Control, Fan Cowl
56J119624	Skins - Pylon
56J119625	Acoustic Panel Assembly - Fan Cowl
56D119626	Doubler - Pylon
56J119627	Splitter Assembly - Fan Cowl
56J119628	Skins - Splitter, Fan Cowl
56E119629	Rings - Splitter, Fan Cowl
56E119630	Pad Assembly - Strut, Splitter
56J119631	Strut Assembly - Splitter
56J119632	Fitting Assembly - Fan Cowl
56D119633	Fitting Assembly - Actuator Clevis
56E119634	Link Assembly - Actuator
56D119635	Fitting Assembly - Actuator Hinge
56D119636	Fitting - Actuator Back-Up
56E119637	Filler - Splitter
56D119638	Fitting Assembly - Splitter
56D119639	Plug Assembly - Splitter
56E119640	Seal Assy. - Core Cowl Extension Ring
56J119641	Housing - Inlet
56D119642	Cone - Inlet
56D119643	Rings - Inlet
56D119644	Ring - Sta. 158.75, Inlet
56C119645	Longeron - Inlet
56J119646	Panel Assembly - Inlet
56D119647	Skins - Inlet

56D119649	Spool - Inlet, Hardwall
56D119650	Spool - Inlet, Acoustic
56D119651	Skins - Inlet Spool, Acoustic
56J119652	Inlet Spool Assembly - Acoustic
56J119653	Inlet Spool Assembly - Hardwall
56D119654	Bellmouth Assembly - Inlet
56D119655	Ring - Bellmouth
56J119656	Ring Assembly - Soft Mount
56D119657	Ring - Soft Mount
56D119658	Skin - Ring, Soft Mount
56E119659	Assembly - Panel, Hardwall, Inlet
56E119660	Assembly - Panel, Acoustic, Inlet
56J119661	Latch Assembly - Fan Cowl
56J119662	Longerons - Core Cowl
56D119663	Close-Out Assembly - Splitter
56E119664	Fillets - Pylon to Core Cowl
56J119676	Seal Assembly - Core Cowl
56J119677	Pylon Assembly - Forward
56J119678	Support Assembly - Pylon, Upper
56D119679	Bar - Upper Tie
56J119680	Frame Assembly - Forward Pylon
56E119681	Wedge - Forward Pylon
56E119682	Tee - Aft Pylon
56E119683	Panel Assembly - Access
56J119685	Boat Tail Assembly - Pylon
56E119700	Seal Assembly - Fan Cowl, Forward
56E119701	Seal Assembly - Fan Cowl
56E119702	Seal Assembly - Fan Cowl
56J119703	Instrumentation Pad Installation - Fan Cowl
56D119723	Rings-Inlet, Spool
56E119726	Panel Assembly - Hardwall, Fan Cowl
56E119727	Panel Assembly - Acoustic, Fan Cowl
56E119728	Panel Assembly - Acoustic
56E119729	Panel Assembly - Core Cowl
56E119730	Panel Assembly - Core Cowl
56E119731	Panel Assembly - Core Cowl
56B119734	Stud Insert - Sound Panel
56A119735	Pod - Panel Support
56E119739	Panel Assembly - Soft Mount
56D119740	Machine Fittings - Soft Mount
56J119741	Cooling Air System - Core Cowl
56B119742	Filler - Core Cowl
56J119743	Kulite Installation - Fan Cowl
56J119744	Tube Assembly - Spreader, Core Cowl
56J119745	Hoisting Equipment
56E119746	Cover - Core Cowl Door Hinge
56D119747	Rings - Kevlar Panel - Inlet

APPENDIX II

UTW CORE EXHAUST NOZZLE DRAWING LIST

4013096-782	Inner and Outer Cylinders
4013096-786	Outer Duct, Acoustic
4013096-787	Centerbody Acoustics
4013096-788	Outer Duct, Hard Wall
4013096-790	Plug, Centerbody
4013096-791	Nozzle, Outer Cowl
4013096-792	Strut
4013096-793	Outer Strut Plate
4013096-794	Inner Strut Plate
4013096-796	Outer Aft Cone
4013096-798	Centerbody, Hard Wall
4013096-806	UTW Flight Exhaust Nozzle
4013096-809	Tube Air Supply
4013096-810	Tube Oil Supply
4013096-811	Tube, Balance Piston Air
4013096-812	Tube Seal Drain
4013096-813	Tube Scavenge
4013096-844	Exhaust Nozzle Assembly